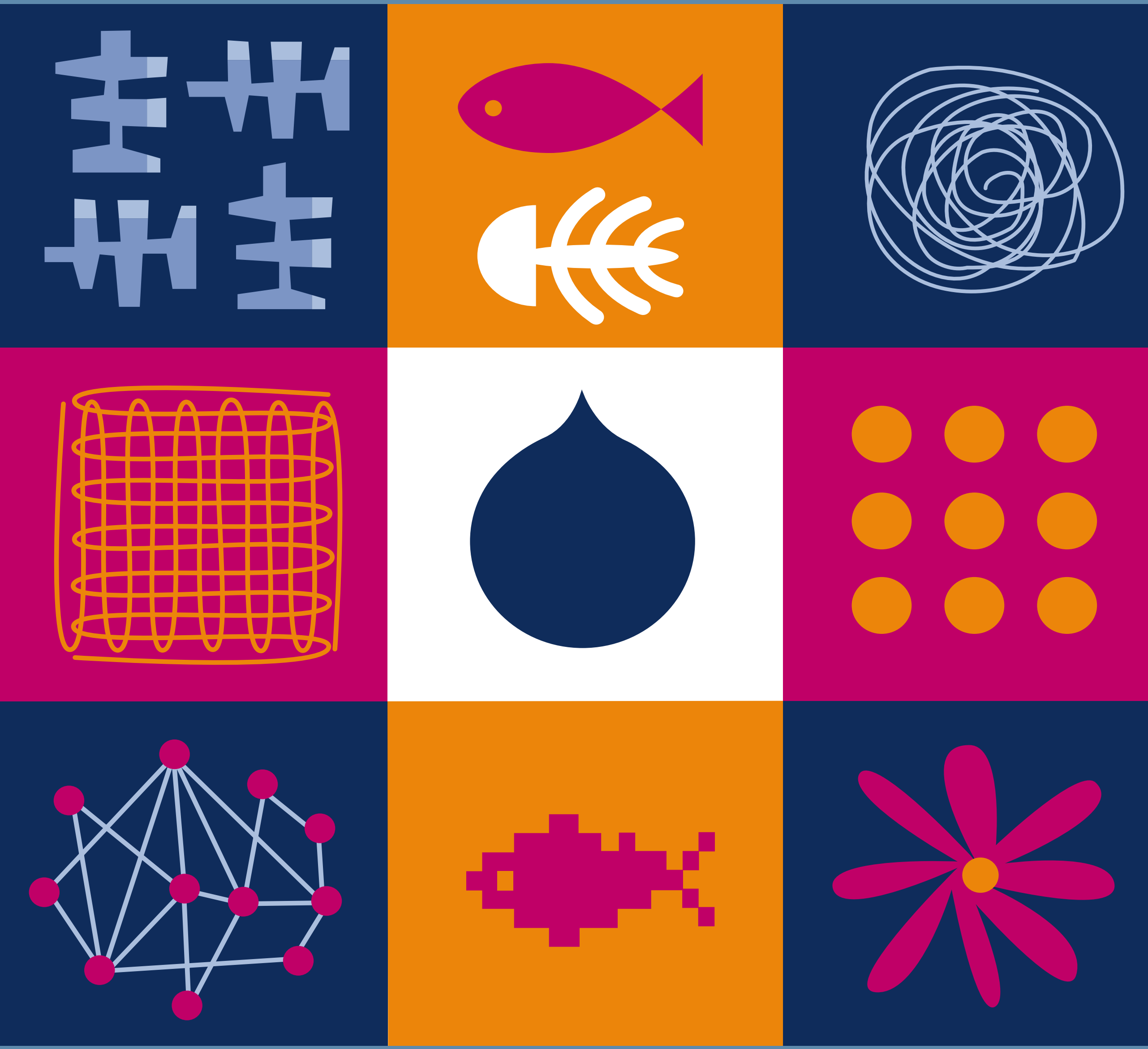
Environment 2001

The Norwegian petroleum sector



OLJE- OG ENERGIDEPARTEMENTET

Ministry of Petroleum and Energy

Environment 2001

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Editor: Øystein Aadnevik, MPE
Edition completed: March 2001

Layout/design: Fasett AS, www.fasett.no
Illustration: Lasse Skarbøvik
Photos: ©Øyvind Hagen, ©Fredrik Refvem, Statoil,
©Victor Lenson Brott, BP Amoco, Norsk Hydro,
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Paper: Munken Lynx 240 g/150 g.
Printer: Gunnarshaug
Circulation: 4 000 Norwegian / 6 000 English

ISSN-1502-3400

Contents

Foreword

The purpose of issuing this environmental publication is threefold:

- To increase the knowledge of environmental issues in the Norwegian oil and gas sector.
- To take a closer look at a topic which both the industry and authorities are particularly concerned about, including the options and challenges faced.
- To underline the Government's goal that Norway should combine her role as a major energy producer with that of being a leader and setting a good example on environmental matters.

"Discharge to sea" is the main topic of Environment 2001. We wish to inform about the challenges and opportunities facing the industry regarding the discharge of oil, organic compounds and chemicals. We also wish to discuss the national policy in this area and assess any environmental impact such discharges could have on the marine environment. To make the presentation more focused we have concentrated on continuous discharges to sea both from well and drilling operations as well as from produced water.

In addition Environment 2001 also contains a factual section. Here we deal with the state of the discharge issue, the environmental effects and measures to reduce the emissions to air and discharges to sea from the offshore operations.

It is our hope that this publication will help to enhance the knowledge about the petroleum activities and what is being done to protect the environment. We furthermore hope to demonstrate that concern for the environment is already an integrated part of the Norwegian petroleum policy.

I would like to extend special thanks to the external reference group comprising representatives of Bellona, the Norwegian Oil Industry Association (OLF) and the Federation of Norwegian Manufacturing Industries (TBL) for constructive input and comments during the work with Environment 2001.

Yours sincerely

Olav Akselsen
Minister of Petroleum and Energy

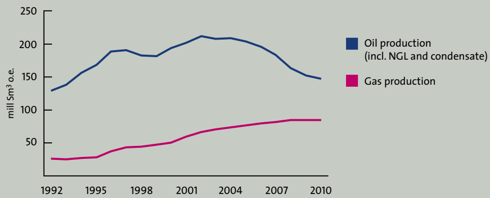


Figure 1 Production of oil and gas on the Norwegian continental shelf. *(Source: MPE/NPD/FIN)*

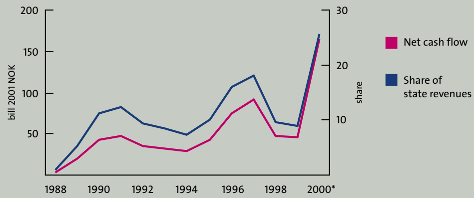


Figure 2 Government's net cash flow from petroleum operations 1988-2001. *(Source: MPE/NPD/FIN)* *estimate

Petroleum activities in Norway

Facts about the petroleum sector

- accounted in 2000 for around 48% of the value of Norwegian exports
- contributed 25% of the state's overall revenues in 2000 through:
  - revenues from the State Direct Financial Interest (SDFI)
  - taxes and duties from the oil companies
  - dividends from Statoil and Norsk Hydro
- Statfjord/Snorre, Gullfaks and Oseberg, which account for well over 27% of Norway's production of oil, have all passed their peak level of production and now have declining output
- none of the oil discoveries made in recent years has been of this magnitude
- when Draugen came on stream in 1993 it marked the introduction of the Norwegian Sea as a production area
- gas will gradually assume increasing importance compared with oil

Oil production on the Norwegian continental shelf started on the Ekofisk field in 1971. Gas exports started out from the same field in 1977. Output grew from year to year until 1997 (see Fig. 1). In 1998, production was somewhat lower than the year before due to diminishing production from mature fields, production regulation to contribute to stable oil prices and postponed start-ups of new fields. Production increased last year and is expected to reach its maximum level next year.

In addition to developments on the continental shelf, shore facilities have been built at Kårstø, Kollsnes, Sture, Mongstad and Tjeldbergodden in order to land gas, and to a greater or lesser degree, process oil from the fields.

Oil and gas are non-renewable resources. The production of oil and gas often generates revenues far in excess of what is normal in other industries. These additional earnings accrue for the most part to the government through taxes and duties as well as through the State's direct interest.

Petroleum operations have contributed enormous revenues to Norwegian society. Total revenues from the sector have varied over time in step with changes in price and production, see Fig. 2. Petroleum revenues are to a large degree determined by the world market price for crude oil, the exchange rate of the dollar and production costs. This means that the government loses considerable revenues when the price of oil is low. The government's annual cash flow from the sector is reduced by an estimated NOK 1 billion each time the price of oil drops by one krone.

The demand for goods and services precipitated by activities on the Norwegian continental shelf has created major ripple effects in society. A high percentage of the contracts for exploration, development, production, transport and removal of obsolete equipment have been won by Norwegian industrial companies in competition with international competitors. The strength Norwegian offshore suppliers have consequently gained in recent years has allowed them to make gradual headway in the international market as well. Being competitive on the world market is vital if the industry is to have a future beyond its lifetime on the Norwegian continental shelf.

Environmental protection by the authorities

Environmental policy has historically been based on direct regulation of environmentally harmful emissions and discharges. In recent years Norway has made increasing use of economic measures such as taxes. In a number of other countries the authorities have to a greater extent chosen to sign agreements with the industry in order to limit the environmental impact of various types of emissions and discharges.

The authorities regard close co-operation with the industry as a precondition for achieving established environmental goals without imposing too high economic costs on society. In order to further develop such co-operation in the oil industry, MILJØSOK was founded in 1995. The objective of this environmental initiative is to maintain the Norwegian continental shelf's position as an exponent of environmentally friendly and competitive oil and gas activities in the future. Oil companies, the contracting industry, authorities and other affected groups are all a part of the effort.

Exploration phase

The objective of opening new exploration areas is to initiate exploration to find profitable petroleum resources for future development and production. The most important environmental consequence of exploration activities is the danger of acute discharges of oil (oil spills), which are potentially dangerous to larvae, fish eggs, fish, seabirds and marine mammals, as well as life along the shore.

Before a new area is opened to activities, thorough analyses are carried out to see how harmful exploration may be to the environment. The obligation to carry out such impact studies is laid out in the Petroleum Act. The studies are circulated for public comment and are then presented to Norway's national assembly, the Storting. Special impact studies have been carried out for the Norwegian Sea, the Skagerrak and the southern Barents Sea.

Since the end of the 1980s a number of environmental and fishery-related studies have been undertaken concerning issues in the Barents Sea in general and the areas north of Bjørnøya in particular. Here problems of oil and ice are particularly prominent. In view of the marketing outlook, the geological uncertainty and the foreseeable technological development concepts for this geographical area, as well as its environmental vulnerability, there is great uncertainty associated with the commercial interest in this area. Therefore the Ministry does not plan to carry out new environmental and fishery studies of the Barents Sea North either this year or the next few years.

The Ministry will start the work of assessing the need of and interest in petroleum activities in coastal area off Nordland (Mid-Norway) beyond those locations that have already been opened up. The findings of this work will be closely evaluated before possible new steps are taken. Before opening new areas the Storting undertakes an overall evaluation of the environmental considerations, fishery interests, the interests of other affected industries and the benefits of extracting oil and gas. Areas where the drawbacks outweigh the benefits are not opened to exploration activities. The Storting can also impose special conditions on certain areas, such as no-drilling periods.

The government also lays down specific requirements in areas opened to exploration in order to limit conflicts of interest between environmental and fishing interests. Examples of such requirements can be limitations on when drilling can take place and specific emergency preparedness requirements to limit the damage done by any oil spills.

Once an area is opened to exploration activities, blocks in the area can be advertised. Production licences are awarded to the companies which the government, on the basis of an overall evaluation, believes can best realise the estimated assets in the area.

There is general agreement on the need to improve the current knowledge on the long-term effects of discharges to sea. Studies have commenced on identifying the knowledge requirements and thus shed light on the need of research.

An overall review of ongoing work and existing studies will be undertaken of the impact on the environment and fisheries of the offshore operations in the North Sea. The purpose is to identify the need of any new studies of the overall consequences of existing and future petroleum activity in the North Sea.

Development and operation phase

Once commercially viable discoveries have been located, the next phase is development and operation to realise the assets.

Before the participants in the production licence can develop a discovery, the Petroleum Act requires that a plan for development and operation (PDO) and possibly a plan for construction and operation (PCO) is approved by the authorities.

As part of the PDO/PCO process, the developer must submit a study covering the impact on nature and the environment if the discovery in question is realised. The study describes any environmental effect of expected emissions and discharges, and a systematic review of the costs and benefits of possible mitigating measures is undertaken. Both the programme and the impact study itself are circulated for comment among affected social interests. In addition new rules have been introduced on impact assessments relating to developments that could cause environmental harm across the boundaries.

Depending on the scope of the development, the PDO/PCO is approved by the King in Council or the Norwegian Storting (national assembly) based on an overall evaluation of the project. Environmental protection is one of the criteria in this evaluation.

In addition to the danger of acute discharges, the operating phase entails continuous emissions and discharges to air and sea.

These include:

- Discharge of water containing residual oil and chemicals
- Emissions of carbon dioxide (CO_2) and nitrogen oxides (NO_x) from energy production and flaring
- Emissions of non-methane volatile organic compounds (nmVOC) from fields based on buoy loading of oil

In order to limit the effects of emissions and discharges on the environment during the operating phase, the authorities use the following policy instruments:

CO_2

Under CO_2 Tax Act, a CO_2 tax must be paid for the use of gas, oil and diesel in connection with

petroleum activities on the continental shelf. Flaring gas beyond what is necessary for safety reasons during normal operations is not permitted under the Petroleum Act without the approval of the Ministry of Petroleum and Energy. However, in Storting White Paper no. 39 (1999–2000) it was proposed to discontinue the rule of applying for a permit to flare and/or cold vent petroleum. The proposal was approved by the Storting.

NO_x

Beyond the PDO, NO_x is currently not regulated on the continental shelf during the operating phase.

nmVOC

The emission of nmVOC associated with loading and storing of crude oil is now governed by emission permits under the Pollution Control Act.

Oil, organic compounds and chemicals

Companies must apply to the Norwegian Pollution Control Authority (SFT) for permits to discharge oil, organic compounds and chemicals into the sea. The SFT issues permits in accordance with the provisions of the Pollution Control Act. Under the Pollution Control Act, the operating companies have the responsibility and obligation of establishing the necessary emergency preparedness to deal with acute pollution. Municipal and state emergency preparedness plans provide further protection.

Closing phase

Petroleum production on several fields on the Norwegian continental shelf has now ended or is in the process of ending. The authorities have made decisions regarding the disposal of disused installations on Nordøst-Frigg, Øst-Frigg, Odin, Mime, Tommeliten Gamma and Lille-Frigg.

The Ministry received in the autumn of 1999 a plan for the decommissioning of Ekofisk I. A Proposition on removing the installations in the Ekofisk area is expected to be submitted to the Norwegian Storting in 2001.

The provisions of the Petroleum Act regarding the disposal of installations will be enforced in compliance with relevant national and international obligations. In July 1998, the Commission for the Convention for the Protection of the Marine Environment of the North East Atlantic (OSPAR) passed a general prohibition against the disposal of disused offshore installations in the convention area. The prohibition makes exceptions for concrete installations, certain parts of large steel installations and installations which for unforeseen circumstances are more justifiably disposed of at sea. Before an installation is disposed under this exception, consultations must be carried out with the other parties to the convention.

The main rules otherwise are a consequence of the UN Convention on the Law of the Sea of 1982 and guidelines adopted pursuant to it by the International Maritime Organization (IMO). These rules mean that a major portion of the Norwegian installations which are not reusable will be brought back to shore for recycling or disposal.

The OSPAR decision does not cover pipelines and cables. In 1996 a three-year study programme aimed at clarifying the effects of various disposal alternatives for pipelines and cables was commenced. A Storting White Paper on this subject was submitted in 2000 based on this study programme. In addition to a review of these studies the White Paper contained general principles for the disposal of abandoned pipelines and cables, while also dealing with individual issues.

Status of emissions and discharges

The petroleum sector accounts for a substantial percentage of Norwegian emissions of carbon dioxide (CO_2), nitrogen oxides (NO_x) and non-methane volatile organic compounds (nmVOC). In addition, the sector generates minor emissions of methane (CH_4) and marginal emissions of sulphur dioxide (SO_2). The data on emissions of CH_4 and SO_2 are, however, poor and many of the estimates are highly uncertain. Operations also cause discharges of oil and various chemicals into the sea.

The various components of emissions contribute to different environmental problems, each of which is international in nature. In dealing with transnational pollution and emissions and discharges in common areas such as international waters, it is necessary for the involved countries to work together to achieve desired environmental goals.

Global environmental problems

Both CO_2 and CH_4 are greenhouse gases that contribute to the greenhouse effect. These are regulated internationally through the UNFCC. Norway's obligation in accordance with the Kyoto Protocol means that average emissions for the years 2008-2012 may increase by 1% in relation to the 1990 level. Compared to the current level, this means a reduction of about 6%. This commitment can be met through domestic reductions and partly in other countries through the use of the Kyoto mechanisms.

Regional environmental problems

NO_x, SO_2 and nmVOC contribute to transboundary regional environmental problems such as acid rain, overfertilization and ground-level ozone. They also cause certain local pollution problems. Emissions of these gases are regulated through protocols under the LRTAP Convention. In December 1999 Norway, together with other European countries, USA and Canada, signed a new protocol (the Gothenburg Protocol) which seeks to solve the environmental problems which acidification, eutrophication and ground-level ozone represent. Under the protocol Norway must reduce its emission of NO_x to 156 Kt by 2010, which represents a cut of 29% compared with the level of emissions in 1990. For nmVOC the commitment is about identical to the one Norway has accepted under the existing VOC Protocol. According to the latter the requirement is that the emissions of nmVOC from all of mainland Norway and the Norwegian economic zone south of the 62nd parallel are to be reduced by 30% by 1999 compared with the level in 1989. Norway has not met this obligation within the deadline.

Local environmental problems regulated internationally

Oil and chemical discharge have local effects in the immediate vicinity of the installations. The discharges are regulated internationally through the OSPAR Convention because they take place in international waters and are thus not the concern of only one country.

In accordance with the international agreements mentioned above, Norway is obliged to limit its emissions of the various substances. How this will affect the petroleum sector will depend on the framing of the individual agreement. Emission ceilings are usually specified for each country in the emission agreements. The framing of the agreements is decisive as to whether the obligatory emission limits must be carried out entirely within the borders of each country, or whether the reductions can also be implemented in other countries where the reduction cost may be lower. The costs of reducing emissions and discharges from the various sources, and possibly in other countries as well, will be decisive for to which degree measures will be implemented vis-à-vis the petroleum sector.

For discharges to sea a maximum oil content level has been set internationally for discharges of water. In other words, no ceiling has been specified for total discharges, as is the case with air emission agreements. The discharge of chemicals is governed internationally by categorising the environmental impact of each chemical.

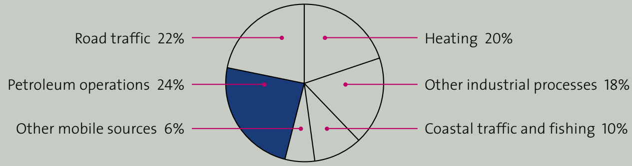


Figure 3 Sources of Norwegian emissions of CO_2, 1999.
(Source: Statistics Norway/Norwegian Pollution Control Authority)

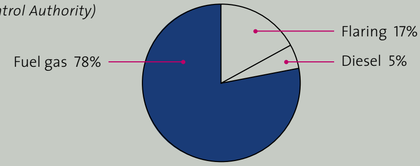


Figure 4 CO_2 emissions from oil and gas production broken down by source, 2000. *(Source: MPE/Norwegian Petroleum Directorate)*

Carbon dioxide CO_2

Environmental effects of CO_2

- The most important greenhouse gas contributing to the greenhouse effect, which in turn can lead to global warming
- According to the UN's Climate Panel: "The balance of evidence suggests a discernible human influence on global climate."

Human-generated emissions of CO_2 are largely connected with the burning of fossil fuels. In a national context petroleum operations account for about 24% of the CO_2 emissions (see Fig. 3), and this percentage is expected to increase with time. Other major sources of emissions in Norway are road traffic and other mobile sources, heating and emissions from various industrial processes.

As Fig. 4 shows, CO_2 emissions related to the production[1] of oil and gas on the continental shelf mainly stem from the burning of gas in turbines and flares, and the burning of diesel on installations[1]. Of the fossil fuels, natural gas gives off the lowest CO_2 emissions when burned. Beyond this, CO_2 emissions are connected with gas terminals on shore, exploration activities and indirectly to nmVOC emissions from the loading of crude oil. Total emissions of CO_2 from the sector have grown year by year, mainly as a result of increased activity. The trend in recent years and prognosis for the years to come are shown in Fig. 5. Higher overall emissions do not mean that environmental improvements are absent. Improvements in energy utilisation and reductions in flaring have, however, not been great enough to outweigh the increase in energy use that the greater activity has contributed to. One indication that activities have become more efficient is that CO_2 emissions per produced oil equivalent have been reduced by about 24% from 1990 to 2000 (see Fig. 6).

The reduction per unit is inter alia attributed to:
- General improvements in technology
- Emission-reducing steps, inter alia because of the introduction of the CO_2 tax in 1991
- Other factors, including changes in the production percentage of various fields and changes in the maturity of major fields

Emissions connected with producing a unit of oil or gas vary both between fields and over the lifetime of the field. Reservoir conditions and transport distance to the gas market mean that the need for energy, and consequently emissions, varies among the fields. The variability of emissions over the life of the field is due inter alia to the rising percentage

[1] The historical figures for the emission of CO_2, NO_x and nmVOC from offshore operations are preliminary.

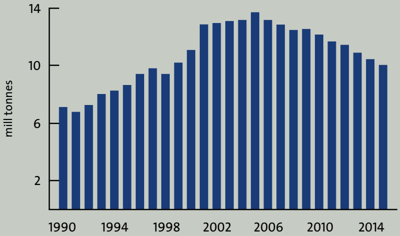


Figure 5 Total emissions of CO_2 from the Norwegian petroleum sector. *(Source: MPE/Norwegian Petroleum Directorate)*

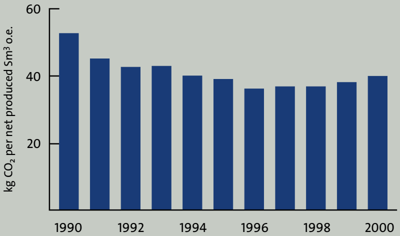


Figure 6 Emissions of CO_2 per produced unit. *(Source: MPE/Norwegian Petroleum Directorate)*

of water in the well stream as fields age. Since it is largely the total quantity of liquid (water, oil and gas) that determines energy requirements in the processing plant, a field will have higher emissions per produced unit as it ages. This is one of the reasons why we have seen a slight increase in emissions per unit in recent years. Figures from the Norwegian Petroleum Directorate in 2000 reveal an increase in the overall emission of CO_2 from the offshore sector from 1999 to 2000.

Future trends on the Norwegian continental shelf in the direction of more mature fields and relocation of activities northwards will consequently cause emissions to increase per produced unit. Continued efficiency gains in power production and more efficient energy use are necessary to limit the expected increase in emissions.

The development of combined solutions for power production offshore and reinjection of CO_2 from produced gas on Sleipner Vest are examples which show that the Norwegian continental shelf is far ahead in terms of employing environmentally efficient solutions. To avoid exceeding sales specifications, it was necessary to reduce CO_2 content in the gas produced on this field. This is the first time that CO_2 removed from produced natural gas has been injected to subsea reservoirs. Thanks to this system annual emissions of about 1 million tonnes of CO_2 emissions are avoided.

In order to understand how high emissions of greenhouse gases from activities on the Norwegian continental shelf are in comparison to similar operations in other countries, some comparisons of emissions per produced unit of oil and gas in various countries have been made. It must, however, be said that there are many uncertainties regarding the reliability of such comparisons.

In a study done by SINTEF, greenhouse gases on the Norwegian continental shelf were compared to similar emissions in other countries including Russia, the Netherlands, Britain and the US. Gas production-related CO_2 emissions in Russia were not available.

Activities on the Norwegian continental shelf did well in the study. One example is that the production of an oil or gas unit on the British continental shelf – which is perhaps the most comparable to activities on the Norwegian continental shelf – generates emissions that are more than three times higher than similar production on the Norwegian continental shelf.

Technology that will be implemented to reduce CO_2 emissions:

- Removal of CO_2 from the well stream and subsequent depositing on Sleipner Vest
- Utilisation of exhaust heat in the process system.
- More efficient energy production, e.g. combined heat and power on Oseberg
- Optimal dimensioning of pipelines
- Replacement of old installations, e.g. Ekofisk
- Increased use of gas engines with higher efficiency than gas turbines
- Optimisation of new fields with respect to energy use and utilisation

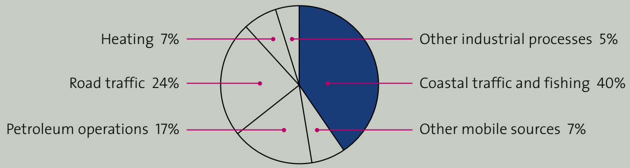


Figure 7 Sources of NO_x emissions in Norway, 1999.
(Source: Statistics Norway/Norwegian Pollution Control Authority)

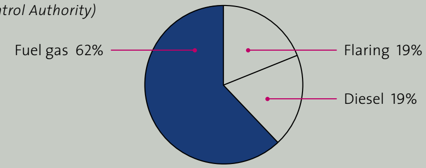


Figure 8 NO_x emissions from oil and gas production broken down by source, 2000. *(Source: MPE/Norwegian Petroleum Directorate)*

Nitrogen oxides NO_x

Environmental effects of NO_x

- Harm to fish and animal life through the acidification of river systems and soil
- Damage to buildings, stone and metals as the result of acid rain
- Eutrophication resulting in changes in the composition of species in the ecosystem
- Damage to health, crops and building as the result of the formation of ground-level ozone when NO_x and nmVOC are exposed to sunlight

NO_x is formed mainly by burning fossil fuels. The quantity of emissions depends on both combustion technology and how much fuel is burned. For example, combustion in gas turbines produces lower emissions of NO_x than combustion in diesel engines.

Mobile sources account for the largest part of Norwegian NO_x emissions (see Fig. 7). The petroleum sector contributes 17%. As for CO_2 gas combustion in turbines and flares together with diesel consumption on the installations are major sources of emissions in the sector (see Fig. 8). In addition, there will also be some emissions connected with exploration operations and the gas terminals on land.

As Fig. 9 shows, emissions of NO_x from the sector have grown steadily since 1990. The main reason for this is that the increased activity has meant higher energy needs, thereby increasing emissions. The change in emissions per produced unit gives us an indication of the development in the efficiency of operations on the continental shelf. Emissions per produced unit are shown in Fig. 10.

Major reasons for the fact that NO_x emissions have not increased as much as the production of hydrocarbons are the same as for CO_2:

- General technological progress
- Emission-reducing steps including improved efficiency in power supplies because of the introduction of the CO_2 tax
- Other conditions such as changes in the production percentage of various fields and changes in the maturity of major fields.

The fact that there is a close connection between the development of both CO_2 and NO_x is natural since the supply of power and flaring are main sources of both emissions.

To gain an understanding of emissions on the Norwegian continental shelf compared to similar activities in other countries, it is practical to compare various countries' emissions per produced oil equivalent. It must be underlined that for a number of reasons there is considerable uncertainty connected with such comparisons between countries.

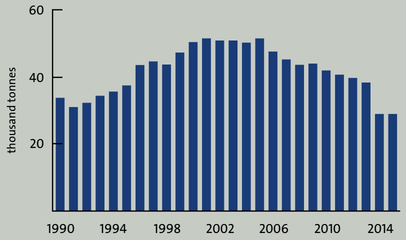


Figure 9 Emissions of NO_x from Norwegian petroleum sector. *(Source: MPE/Norwegian Petroleum Directorate)*

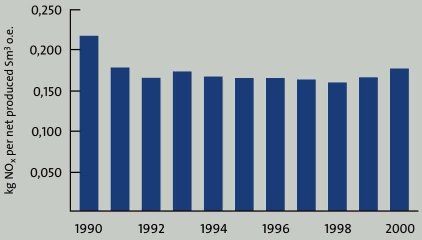


Figure 10 Emissions of NO_x per produced unit. *(Source: MPE/Norwegian Petroleum Directorate)*

A study done for MILJØSOK indicates that emissions of NO_x on the Norwegian continental shelf are lower than in the countries with which it is natural to compare ourselves.

Norway has signed a new international protocol governing i.a. the emission of NO_x. Below possible measures are outlined to reduce NO_x emissions, but it is too early to say how this agreement will impact on the petroleum sector.

Measures to reduce NO_x emissions:

- low NO_x burners in new turbines. These have the potential of reducing emissions from a gas turbine by almost 90%
- more efficient power generation
- optimisation of new installations with respect to energy consumption and energy production

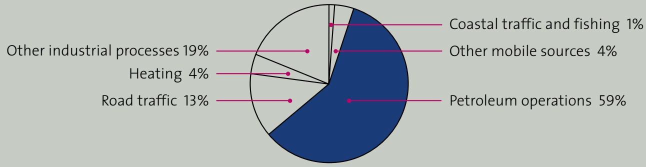


Figure 11 Sources of nmVOC emissions from the petroleum sector, 1999.
(Source: Statistics Norway/Norwegian Pollution Control Authority)

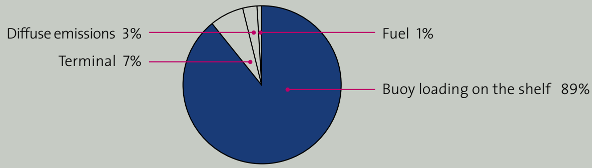


Figure 12 Sources of emissions of nmVOC from the petroleum sector, 1999.
(Source: MPE/Norwegian Petroleum Directorate)

Non-methane volatile organic compounds (nmVOC)

Environmental effects of nmVOC

- The formation of ground-level ozone may damage a person's health as well as crops and buildings
- It may cause respiratory injuries in the event of direct exposure
- An indirect contribution to the greenhouse effect because CO_2 and ozone are formed when nmVOCs react with air in the atmosphere

nmVOC is the term for volatile organic compounds that evaporate from crude oil and other substances. The various elements of nmVOC have different implications for the environment. It is, however, normal to view all gases as a whole when complying with international emissions obligations.

The petroleum sector is the main source of emissions of nmVOC in Norway, accounting for 59% of the national emissions. As Fig. 11 shows road traffic and other industrial processes are other major sources of emissions. In the petroleum sector the bulk of the emissions stem from buoy loading of crude oil and from shore terminals. Some emissions also occur at gas terminals and during minor leaks (see Fig. 12).

Until now emissions from buoy loading on the continental shelf have largely been connected with loading buoys on Statfjord and Gullfaks. Other big fields like Oseberg and Ekofisk are based on the transport of oil by pipelines to shore. There are big differences in the emissions from loading one unit of oil on the various fields. One of the main reasons is that the content of light gases in the oil varies between the various fields.

Several of the new developments on the continental shelf are based on the use of floating storage ships. This type of development solution – in which the oil is stored under atmospheric conditions – may cause higher emissions of nmVOC than is the case on fields where oil is stored in the base of the platform (Statfjord and Gullfaks). This is because emissions will also occur during production in the stores using such solutions.

For many years the oil companies have worked to make technology for recovering nmVOC available to shuttle tankers, the ships that transport oil from the fields to the receiving ports. Two alternative solutions are undergoing full-scale testing. Both will be able to reduce emissions from a loading by approx. 70%. One of the concepts entails reinjecting nmVOC into the oil cargo and will expectedly be the most likely candidate for older shuttle tankers. The second concept involves condensing and

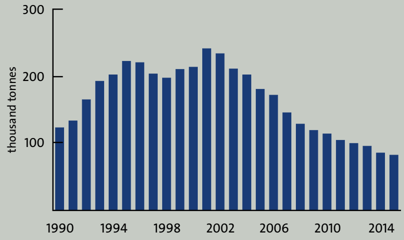


Figure 13 Total emissions of nmVOC from the Norwegian petroleum sector. *(Source: MPE/Norwegian Petroleum Directorate)*

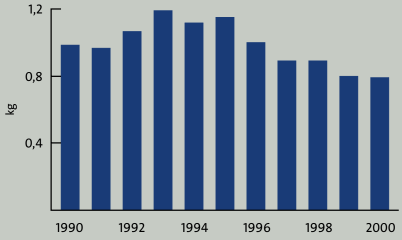


Figure 14 nmVOC emissions per produced unit. *(Source: MPE/Norwegian Petroleum Directorate)*

using it as fuel to run the shuttle tankers. This technology will probably be more workable for new ships. Condensed nmVOC is a relatively clean fuel, so that the emissions of environmentally harmful gases from the operation of the shuttle tankers will also be greatly reduced with this alternative.

The prognosis for emissions of nmVOC from the sector shows a falling trend after the year 2001 (see Fig. 13). This is due both to the fact that the oil production will reach peak levels in the course of a few years, and that one expects recovery equipment to be installed in keeping with demands set out in the Pollution Act.

Sture is first

In 1996 a nmVOC recovery plant was commissioned at the crude oil terminal on Sture. The plant has the potential to reduce nmVOC by about 90% per loading, and is the first of its type to be installed at a crude oil terminal. To use the plant, loading ships must be fitted with coupling equipment. Realised recovery in the first year of operation was just under 40% as only a limited number of the tankers were fitted with the necessary equipment. To promote the installation of coupling equipment on the tankers, considerably lower port fees are offered to ships that have installed such equipment.

International comparisons indicate that emissions of nmVOC per produced quantity of oil and gas are higher on the Norwegian continental shelf than in other countries. The high percentage of buoy loading of oil on the Norwegian continental shelf could be an explanation for why the emissions are higher than in the other petroleum provinces that were examined.

Measures to reduce nmVOC emissions:

- Recovery of nmVOC on Sture
- Recovery of nmVOC on the continental shelf:
  - reinjection into the oil cargo
  - condensing for use as fuel on board the shuttle tanker

Oil, organic compounds and chemicals

Environmental effects of oil discharges:

- Spills/acute discharges can harm fish, sea mammals, seabirds and shore zones
- There is considerable uncertainty about the environmental consequences of operational discharges. To this day no environmental damage has been proven and considerable research is taking place in the area, particularly on the long-term effects.

Environmental effect of organic compounds

- There is great uncertainty on the long-term effects of dissolved organic compounds such as PAH compounds and alkyl phenols. Considerable research is being conducted in this area.

The environmental effects of chemicals:

- Discharges consist of a variety of substances with wide-ranging potential effects on the environment
- Most of the chemicals used (above 90%) are assumed to have little or no environmental effect
- Still little is known about the possible harmful effects of chemical discharges.
- Several of the chemicals are locally poisonous to a certain extent. Studies show that they are diluted in the water column so that they do not represent a major acute environmental hazard outside the immediate vicinity of the discharge
- A small portion of chemical discharges can have extremely serious environmental consequences, including hormonal disturbances and bio-accumulation.

Oil

Total discharges of oil from Norwegian petroleum operations account for 2% of the total supply to the North Sea. The main supply of oil to the North Sea comes from shipping and the mainland via rivers. The oil discharges from the petroleum sector mainly stem from ordinary operations, although acute discharges or spills occur.

Organic compounds

Organic compounds are naturally present in reservoirs and are brought to the surface through the well with the produced water. The most important compounds from an environment point of view are and alkyl phenols.

Chemicals

Chemicals is a generic term for all additives used during drilling operations and in the production of oil and gas. It would be impossible to run efficient oil and gas operations without the use of chemicals.

Considerable efforts are therefore concentrated on developing chemicals that do the least possible harm to the environment during use. To ensure protection of the environment when the companies select chemicals, the CHARM model is used.

This model has been developed by the countries participating in OSPAR. Some development work still remains before the model is adequate as a tool in deciding choice of chemicals.

When looking at the environmental effects of chemical discharges it is important to differentiate between:

- Discharges of largely harmless and more harmful chemicals
- The quantities that are used and discharged
- Where and under which conditions discharges are made, the conditions in the recipients.

More than 90% of the chemicals used in the Norwegian petroleum operations consist of chemicals that are thought to have little or no effect on the environment. A large proportion of these chemicals are substances that exist naturally in seawater. The remaining percentage include chemicals that have an effect on the environment or whose potential effect are not well enough documented.

In 1999 46% of the quantities used were discharged, including the water in which the chemicals were dissolved. The figure for 1989 was 64% (excluding water). The chemicals not discharged are dissolved in the oil, disposed of in the subsoil or treated as waste.

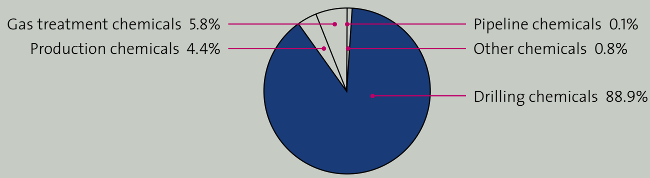


Figure 15 Chemical discharges on the continental shelf broken down by activity, 1999. *(Source: Norwegian Pollution Control Authority)*

Drilling

As Fig. 15 shows drilling operations are clearly the largest source of discharges of chemicals on the continental shelf. Changes from year to year in overall discharges of chemicals are therefore largely caused by changes in the number of wells drilled (see Fig 16).

Since 1991 the discharge of oily cuttings has been banned on the Norwegian continental shelf. As Fig. 17 shows the ban has helped to significantly reduce oil discharges from operations in comparison to what they would have been with continued discharge of oily cuttings.

New drilling methods and new drilling technology have, together with increasing reinjection of cuttings, meant that discharges per metre drilled have gone down in recent years, see Fig. 18. Since the use of water-based drilling fluids required greater use of chemicals, the switch to this type of drilling fluid as a result of the prohibition on the discharge of oil-based drilling mud has had the opposite effect. As previously mentioned, the oil containing drilling mud accompanying cuttings is no longer discharged on the Norwegian continental shelf. Recycling, subsea injection and disposal on land are alternative ways of avoiding drilling discharges.

Produced water

The main source of oil released into the sea from daily operations is discharges of water that come up with the oil and gas from the well (produced water), see Fig. 19. Although the water is carefully filtered before it is discharged, it still contains oil residues and dissolved organic compounds. In 1999 8,4% of all produced water was reinjected.

The average concentration of oil in produced water on the continental shelf has been slowly diminishing. Under the OSPAR Convention the oil content of water discharged into the ocean should not exceed 40 g/m3 (milligrams per litre). The annual average for Norwegian installations in 1999 was approx. 25 g/m3 (milligrams per litre). This figure of concentration has been fairly stable since 1990 (see Fig. 20).

Several of the largest fields are now so old that more water is now being produced per unit of oil and gas from the wells than before. This increases the volume of produced water which by itself increases discharges of oil. In recent years reinjection of produced water has commenced on an increasing number of fields on the continental shelf.

Discharges of production and injection chemicals have increased in recent years. This is mainly because of greater use of subsea templates and greater quantities of water injection. These activities are normally dependent on using chemicals. The content of production chemicals in produced water does not, however, show any clear trend (see Fig. 21).

Acute spills

The damage to the natural environment because of oil spills depends more on the circumstances than the size of the spill. The spill site, time of year, wind strength, current and effectiveness of the

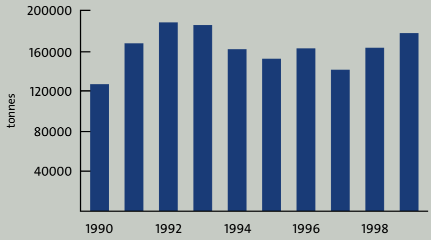


Figure 16 Total discharges of chemicals from Norwegian petroleum activities. *(Source: MPE/Norwegian Petroleum Directorate)*

Injection chemicals not measured before 1991.

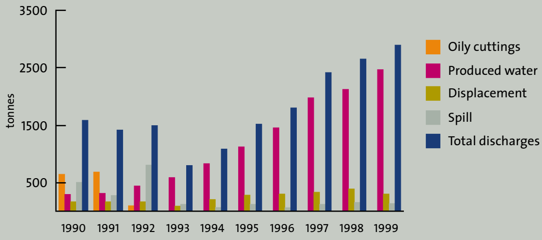
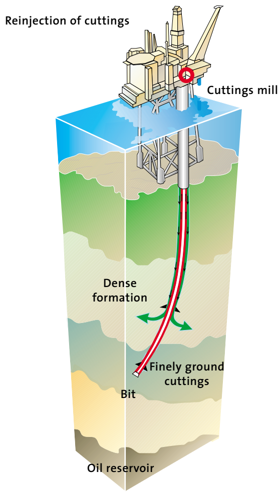


Figure 17 Total oil discharges broken down by source. *(Source: Norwegian Pollution Control Authority/ Norwegian Petroleum Directorate)*

response to the emergency all play a vital role. Most of the serious oil spills in Norway have involved ships near the coast. There have been no incidents of major oil spills that have reached shore from petroleum activities on the Norwegian continental shelf. Expanded petroleum activity towards coastal and more environmentally sensitive areas than earlier will increase the risk of damage from serious oil spills from activities on the installations and oil tankers loading on these fields.

There have been relatively many oil spills from installations on the continental shelf (see Fig. 22). The total volume of oil discharged in connection with oil spills is as previously mentioned nevertheless extremely limited in relation to the supply from other sources.



Zero discharge strategy for discharges at sea

Zero discharge does not mean the end of all types of discharges and consequently the term can be somewhat misleading. Zero discharges is a strategy that can be achieved with a continuous reduction of environmentally harmful emissions towards a practical zero level, in which the damage to the environment depends on the content of potentially environmentally harmful chemicals in addition to the time and place of discharge. The degree of environmental damage depends on the discharge's content of environmentally harmful compounds, and the field-specific discharge and recipient conditions. For the new independent developments the main rule will be zero discharges to sea. A more detailed description will also be given of what the authorities mean by the term zero discharge. It is important that an overall evaluation of discharges to sea, emissions to air and energy conservation be done before the final technological solutions are chosen.

The strategy will also be used for existing installations and for developing smaller fields and discoveries in connection with existing installations. Local conditions at the various installations will affect which solutions will be practical in such cases.

New technology is important in successfully implementing the zero discharge strategy. Technology for separating or blocking water before reaching the installations will be major elements in realising this goal. Separation can take place either down in the well or on the seabed. In addition to reducing discharges to sea, such technology will also have favourable effects on emissions to air and on oil production.

Troll: A Pioneer

The Troll Pilot is a subsea separation unit made to separate produced water from the rest of the well flow in one of the production lines to the Troll C platform. The water is then to be reinjected into the reservoir. In this way both transportation of produced water to the platform is reduced as well as the discharge of oily water.

Such benefits are achieved by down-hole separation, which to date has only been tested in fields located onshore.

Subsea reinjection of produced water is another method that can contribute to a reduction in discharges where practical. The technology is used today on several fields. However it is only at Ula that this is done on a large scale - the other fields have smaller plants or test plants in operation. Reinjection of produced water will be implemented on several recently approved developments and will be particularly interesting on fields and discoveries where there is a need for water injection to create pressure support.

Reinjecting produced water when there is no need for pressure support increases energy use and emissions to air on the installations. In such cases an overall evaluation will determine whether the method is appropriate.

At other fields trials have been carried out to shut off water-bearing layers down in the well. However, such a step would also close off the production of hydrocarbons from these layers.

Technology for removing or reducing discharges of produced water

- Whole or partial subterranean reinjection after separation on the installation.
- Mechanical or chemical shut-off of water-bearing layers in wells
- Separation in the well or on the seabed followed by reinjection

Technology for avoiding discharges of drilling fluids

- Recycling
- Collection and subterranean injection
- Collection and disposal on land

Discharges to sea are further dealt with in the Topic section.

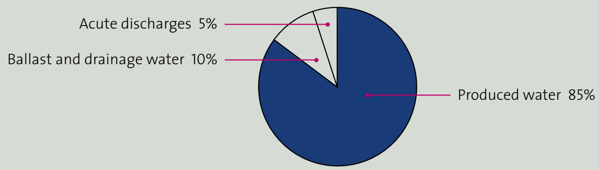


Figure 19 Oil discharges on the shelf broken down by activity, 1999.
(Source: Norwegian Pollution Control Authority/Norwegian Petroleum Directorate)

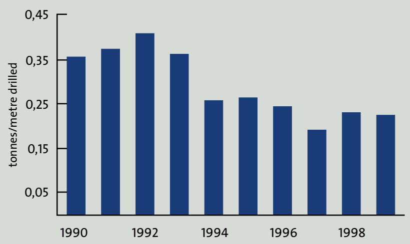


Figure 18 Discharges of drilling chemicals per metre drilled.
(Source: MPE/Norwegian Petroleum Directorate)

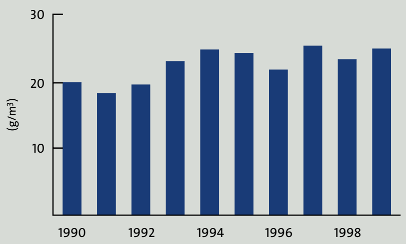


Figure 20 Discharges of oil per cubic metre of produced water. *(Source: Norwegian Pollution Control Authority/ Norwegian Petroleum Directorate)*

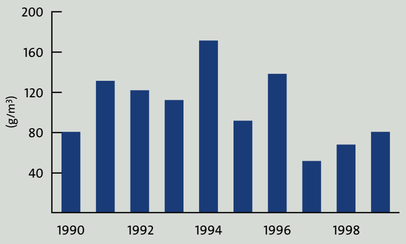


Figure 21 Production, injection and pipeline chemical content in produced water. *(Source: Norwegian Pollution Control Authority)*

The amount of chemicals in 1998 includes water in which the chemicals are dissolved

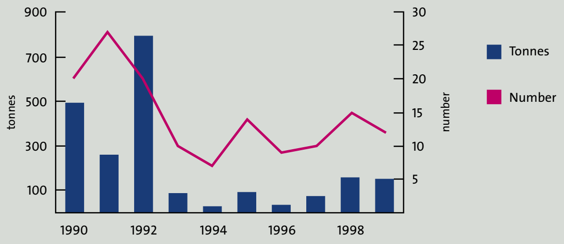


Figure 22 Acute oil spills.
(Source: Norwegian Pollution Control Authority)

Section 2

Discharge to sea

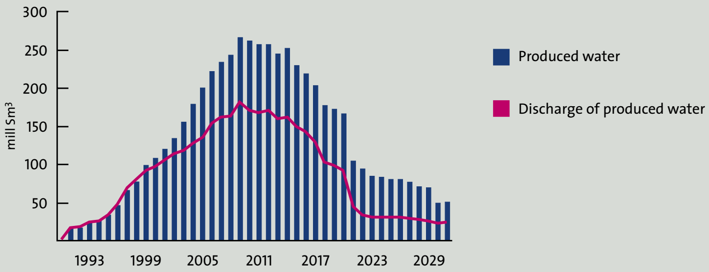


Figure 23 Forecast of the discharge of produced water.
(Source: Norwegian Petroleum Directorate)

Most of the discharges in the next ten years will come from fields currently producing hydrocarbons. These fields will gradually enter a more mature phase with an increasing production of water and constantly growing production-related challenges. Without introducing new measures beyond those currently adopted the discharge of produced water, oil and chemicals from the production process will increase. The forecast for the period up to 2010 shows that the amount of produced water will more than double compared with today's level. But due to increased reinjection of produced water the discharges to sea will only rise by about 50% (see Figure 23). No major changes are expected in the drilling activity the next few years, but the forecasts are uncertain and will of course depend on the fluctuation in the oil price.

Consequently discharges to sea, not least those associated with produced water, represent a considerable challenge for the petroleum industry in the coming years. This is why we have chosen to focus on it in our Topic section in Environment 2001. The Topic section details both the challenges facing the offshore industry in this area as well as the measures that could contribute to solving the problem. Attention is especially paid to the role new technology could play with regard to this issue.

To put a sharper focus on this problem we have decided to concentrate on continuous discharges of environmentally-harmful substances or components associated with drilling and well operations as well as the production process. This means that certain discharges will only be dealt with to a minor degree, such as acute discharge of oil and those discharges linked to the final disposal of installations.

DISCHARGE COMPONENTS

The three most important continuous discharges to sea from offshore operations are oil, organic compounds and chemicals.

As far as oil is concerned the Norwegian offshore sector accounts for approx. 2% of the overall discharge of oil to the North Sea. The main contributors are the rivers and shipping. The main source offshore of continuous oil discharges is drops of oil in produced water (dispersed oil). In addition there is dispersed oil in ballast water and drainage water[1] as well as from acute oil spills (see figure 24). In our account here of the continuous discharge of oil we will for the most part focus on dispersed oil in produced water.

Organic compounds are components that are naturally present in the reservoir and brought up with the produced water. The most important compounds which are potentially the most harmful are PAH compounds and alkyl phenols.

Chemicals is a common term for all the additives and other substances that are used in drilling and production operations related to oil and gas. These are employed amongst other things to ensure regular and safe operations on the installations.

[1] Ballast water comes from the storage cells for crude oil. Drainage water is water from hosing down deck areas where oily water as well as rain water can be expected.

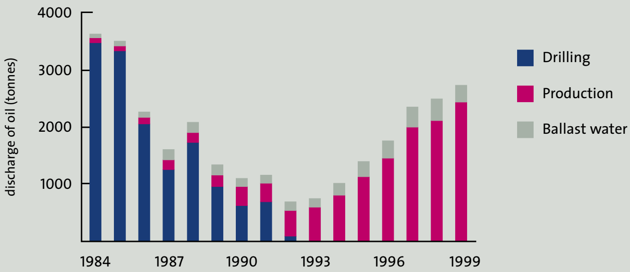


Figure 24 Development of operational oil discharges from 1984-1999.
(source: Norwegian Pollution Control Authority 2000)

The chemicals used in drilling and well operations account for most of the discharge of chemicals, although some chemicals are also used in the production process.

In addition to the three discharge components mentioned here offshore operations also account for some other discharges to sea. These are amongst others non-organic compounds contained in produced water, such as heavy metal (arsenic, nickel, copper, lead) and low-specific activity scale found in the formations. These compounds will only be dealt with below to a minor degree. This is mainly because they are either not very harmful to the environment or that the discharges are very small.

DISCHARGE SOURCES

The most important continuous discharges to sea from offshore operations are from two sources, drilling/well operations and produced water.

Drilling and well operations

The chemicals added to the drilling fluid during drilling operations are the biggest source of chemical discharges on the Norwegian continental shelf. In order to drill exploration and production wells it is necessary to use drilling fluid. This fluid is amongst other things used to grease the drill string and transport drill cuttings out of the well, as well as for pressure control and stabilising the well. The drilling fluid is made up of different chemicals and additives; it can be based on oil or water or a synthetic oily fluid. In relation to the number of metres drilled the consumption of these three types of fluid was respectively 45, 45 and 10%.

Water-based drilling fluids are normally used when drilling the top sections of a well. The drill cuttings containing this fluid are discharged directly to sea. Water-based drilling fluid is cheaper than the other two fluids, but does not have the same good technical qualities. A number of chemicals must be added in order to employ water-based drilling fluid. Work is now in progress both in individual companies and across the field of players to find a standardised water-based drilling fluid to enhance the possibility of reuse. The possibility of reusing it on the installations is dependent on the storage capacity on site. Shipping it to shore and reuse involves transporting a lot of drilling fluid, but generally speaking reuse is beneficial both for the external environment, working environment and economy. By reusing the drilling fluid the total quantity of such fluid can be reduced over time by up to 30%. The environmental qualities of water-based fluids are better than oil-based and synthetic fluids.

Oil-based drilling fluids are relatively speaking low cost and have the best drilling-technical qualities. They are therefore commonly used in the lowest and most complicated sections of a well. Since 1991 there has been a ban on discharging drilling fluids based on oil. The oily drill cuttings must therefore either be reinjected or transported to shore for treatment and disposal.

Synthetic drilling fluids have similar qualities to those based on oil. They were developed to have fluid that was less toxic and more biodegradable than oil-based fluids. However they are more expensive than oil-based fluids and may not be discharged to sea. The Norwegian Pollution Control Authority may, however, grant a permit to discharge drill cuttings containing synthetic oil. The synthetically based fluids have better environmental qualities than oil-based fluids.

From 1998 to 1999 there was an increase in the discharge of drilling waste (drilling fluid and cuttings) of 11%. This was largely due to increased activities. Still, when seen in relation to the number of metres drilled, there has been a positive trend in recent years. A total of 355 000 tonnes of drilling waste was discharged in 1999, of which 322 000 tonnes came from drilling with water-based fluids while synthetic drilling fluids accounted for 33 000 tonnes. The discharge of synthetic drilling fluid decreased from 3 291 tonnes in 1998 to 1 294 tonnes in 1999. According to data from the Norwegian Oil Industry Association's report "Discharges from the Norwegian offshore industry 1999" a total of 108 000 tonnes of drill cuttings and drilling fluid from oil-based operations was produced in 1999, of which 72% was reinjected. The remaining was shipped to shore to an approved facility.

Produced water

An oil reservoir will always have formation water. When the reservoir is emptied of oil, the wells produce more water. The produced water always contains crude oil in a dispersed form, as well as a number of other organic compounds and soluble inorganic compounds from the formation. The produced water furthermore contains chemicals that are used during drilling, production and injection. Despite treating the produced water before it is discharged it will still contain oil residue. It also contains dissolved organic compounds and residual chemical additives.

Produced water accounts for about 84% of the discharge of oil from the offshore industry. In 1999 almost 99 million tonnes of produced water was discharged, compared with close to 91 million tonnes in 1998. This resulted in 2 467 tonnes of oil being discharged with the produced water in 1999 compared with 2 111 tonnes in 1998 (Norwegian Pollution Control Authority 1999).

NATIONAL POLICY

National goals

- Discharge of oil from operations shall not lead to unacceptable harm to people's health or the environment. The risk of harming the environment and other disadvantages caused by acute pollution shall be at an acceptable level.
- Discharge of certain environmentally toxic substances is to be stopped or reduced considerably in the next few years.
- Discharge and use of chemicals representing a serious threat to people's health and to the environment are to be continuously reduced so as to have ended such discharges within a generation (2020).

In Storting White Paper no. 58 (1996-1997) "Environmental policy for sustainable development" the Government furthermore stipulated that a requirement of zero discharge to sea was to be introduced by 2005. The goal of zero discharges can be achieved by a continuous reduction of environmentally-harmful discharges down to a practical zero level, where the environmental damage depends on the contents of potentially harmful chemicals in addition to the time and place of the discharge. The Government's goal is not to permit environmentally-harmful discharges from new fields based on a stand-alone concept. Existing fields will furthermore be reviewed with a view to implementing discharge-reducing measures by 2005.

Means

The Petroleum Act and the Pollution Act are the authorities' most important means to reduce discharges to sea, and are used in all phases of the petroleum operations from exploration to field abandonment. Before an area is opened up to allow oil activities the authorities conduct comprehensive regional environmental impact assessments. Through this process the authorities can shield areas that are especially vulnerable either by banning exploration or have a requirement of drilling-free periods. When awarding new areas the authorities may require e.g. that there be drilling restrictions, restrictions on seismic surveys or contingency plans to combat acute pollution. Before a discovery can be developed the Petroleum Act requires that a plan for development and operation (PDO) be approved by the authorities, in which i.a. the environmental aspects of a field

development are dealt with. In order to discharge any oil or chemicals to sea the companies must apply for a discharge permit from the Norwegian Pollution Control Authority. One of the demands laid down in the discharge permit is the regular monitoring of the marine environment. Regulations are currently being prepared which will set out general conditions pertaining to discharges from planned operations. These regulations will replace individual conditions granted under the Pollution Act. The authorities audit the companies according to Norwegian legislation and internal company requirements.

INTERNATIONAL AGREEMENTS

The London Convention -72 is a global agreement governing the dumping of waste and other materials as well as the burning of waste at sea. Since 1993 the burning of environmentally harmful waste has been banned.

The OSPAR Convention is an environmental agreement based on international law for the protection of the marine environment in the North-East Atlantic Ocean. The parties to the convention develop and follow up their cooperation by participation in the OSPAR Commission. This is where definite measures and programmes are adopted amongst others to combat discharges from the onshore and offshore industry. A total of 15 countries with a coastline or rivers to the North-East Atlantic are members. The convention came into force in March 1998, replacing the Oslo and Paris Conventions. The OSPAR Convention deals with the discharge and dumping at sea. The principle purpose of OSPAR is to prevent and eliminate pollution and protect the marine environment against the harmful effects of human activities.

The OSPAR Convention:

- has stipulated that water discharged to sea may only contain a maximum of 40 mg of oil per litre of water;
- binds the countries to govern their use and discharge of environmentally-harmful chemicals;
- has placed a limit of 1% of oil content in drilling waste during exploration and production;
- has introduced guidelines for the carrying out of regular surveys of the environment around installations;
- has adopted rules for the disposal of abandoned installations;
- has adopted an offshore strategy which is now being followed up.

The North Sea Conference was first held in Bremen, Germany, in 1984. The main purpose of the conference was to reach political agreement on necessary measures to protect the marine environment of the North Sea. This also includes political initiatives to ensure an efficient implementation of existing agreements.

The fourth North Sea Conference was held in Esbjerg, Denmark, in 1995. This conference agreed on a long-term goal of eliminating the discharge of environmentally-toxic substances within a generation. Agreement was also reached on further developing and utilising environmentally-friendly technology to protect the marine environment. The fifth North Sea Conference will take place in Norway in March 2002.

ASSESSING ENVIRONMENTAL IMPACT

What do we know?

The discharge of drill cuttings and drilling fluids cover the seabed and thus alters the chemical and physical conditions on the seabed. Furthermore the mounds of drilling waste, which in some cases can be several metres high, lead to a change in the seabed fauna. The effect on the seabed fauna, caused by water-based drilling fluids, is mainly limited to a 500-metre area from the installation. In connection with older fields, where oil-based fluids have been used, the impact can be seen from 2 to 2.5 kilometres from the installation. Solutions range from leaving the mounds of cuttings, covering them or removing them. Work is in progress to find the best solution. The British oil companies, through UKOOA, have started a common research programme (1999-2002) to study the cutting deposits. The Norwegian Oil Industry Association participates in this work, while at the same time mapping the scope of the drilling deposits on the seabed off Norway.

The discharge of chemicals from offshore operations contains a large number of substances with a greatly varying effect on the environment. The chemicals that are environmentally acceptable constitute an increasing share of the discharges. Some chemicals have a certain acute toxic effect. But studies show that these chemicals very quickly become diluted in the water column and do not represent a serious threat to the environment beyond the immediate vicinity of the discharge. Although practically all the chemicals discharged on the Norwegian continental shelf consist of substances that are assumed to pose a minor threat to the environment, there is uncertainty as to the unknown long-term impact of some of the chemicals.

Environmental impact of oil discharges

- Spills/acute discharge can harm fish, mammals, sea birds and the coastal zone.
- There is uncertainty as to the environmental consequences of operational spills. No environmental damage has been proven to date.

Environmental impact of organic components

- There is uncertainty on the long-term effects of decomposing organic components such as PAH compounds and alkyl phenols. This is subject to considerable research.

Environmental impact of chemicals

- The discharges consist of a long series of substances whose potential effect on the environment varies greatly.
- The majority of the chemicals used (90%) are believed to have little or no environmental impact.
- Still only little is known about any long-term effects of discharged chemicals.
- Several of the chemicals have a certain local toxic impact. Surveys show that they are diluted in the water column and so do not lead to any major acute environmental impact beyond the immediate vicinity of the discharge.
- A small portion of the chemicals discharged may have very serious effects on the environment, including hormone disorders and they can be bioaccumulating.

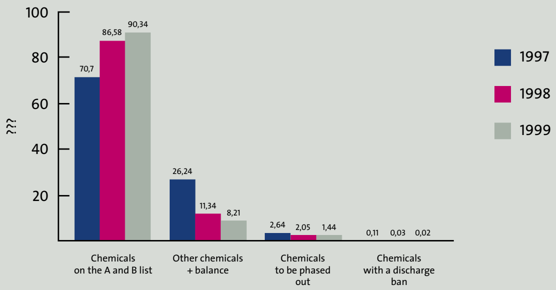


Figure 25 Total discharge of chemicals according to per cent in weight in 1999 compared with 1998 and 1997 per environmental category. *(source: Norwegian Oil Industry Association 2000)*

Produced water contains soluble components (PAH compounds and alkyl phenols) which may have a potential for long-term negative effects. These components have a reduced biodegradability and have in certain instances proven to be accumulating and have impacted negatively on the reproduction ability of marine organisms.

The oil companies have for many years funded research into the long-term effects of discharges to sea. Still the general view persists that there is a need to have more knowledge about this issue. In order to get the most out of the overall research effort (both public and industry-based) the Norwegian Ministry of Petroleum and Energy has taken an initiative for a better coordination of this work.

What do we need to know more about?

The lack of knowledge about the long-term effects of produced water and discharge of chemicals is one of the major gaps in our knowledge on the environmental impact of the current activities. This applies especially to the ecological impact of the discharges and the effect of particularly vulnerable resources and ecological key species. More knowledge is also needed concerning the development of a tool for environmental risk analyses. There is furthermore a need of more research associated with effect of discharges on the deep-water ecosystems and Arctic ecosystems. The fate of drilling chemicals after being discharged to sea is partly unknown. Some will adsorb to particles and sink to the bottom while others will become dissolved in or transported with the water column or be taken up by feeding organisms. Consequently there is a need to test the impact of the chemicals on marine life. Marine species are currently being tested to determine acute toxicity (OECD/OSPAR), but there is also a need of long-term testing (over a 20-30 day period) to be able to determine possible chronic effects.

Petroleum operations will increasingly be carried out in environmentally sensitive areas, where there are important spawning and fishing grounds. In these areas there will be strict demands as to the knowledge about the spreading, impact of small concentrations, long-term effects and bio-accumulation of discharges as well as knowledge about emergency preparedness.

Special deep-water challenges

Before 1997 Norway's deepest offshore well was 523 metres water depth, while current wells exceed 1 300 metres. Eight wells have been drilled in the deep-water areas on the Norwegian shelf. To date both the planning and execution of all the drilling operations in deep water have been successful. Still we have limited knowledge about the spreading and effect of discharges in deep water. Several kinds of plankton, e.g. red feed, stay in the deep-water areas in the winter months and these species play a crucial role in the marine nutrition chain. Acute spills from wells in deep water will behave differently from such spills in shallow areas. Deep-water spills will be spread over larger areas and will be further dispersed into the water column before reaching the surface. This may lead to special requirements relating to contingency plans and oil-recovery equipment. The oil spill contingency plans should be judged on a case-by-case basis.

The Norwegian Deepwater Program (NDP) was started in 1996 by the operators of the deep-water licences. Considerable resources have been used to study the patterns of currents and spreading of hydrocarbons in the event of an uncontrolled discharges in deep water.

Especially vulnerable areas

In recent years the offshore operations have moved northwards and closer to the coast. This means that the oil activities will increasingly be conducted in environmentally-sensitive areas. The coastal population have for generations harvested from the coastal resources, not least by fishing and gathering. In the environmentally-sensitive northern areas the nutrition chains are shorter and fewer. Oil and chemicals dissolve more slowly and plants and animals contain considerably more fat. This makes it easier to accumulate many of the most problematic environmentally-toxic substances. The legislation and practical measures relating to exploration for oil and gas will take into account that the traditional industries are to be able to harvest the resources of the sea also in the future. The wording of the announcements of the last five licensing rounds, from the 15th round (1996) to the North Sea round 2000, requests companies to take particularly into account the fishing activities and the presence of living marine resources during the planning of the drilling activity.

ENVIRONMENTAL MANAGEMENT

The chemicals currently being discharged are becoming more and more environmentally-friendly. This is due to the authorities' ban on the use of chemicals known to be harmful to the environment and active environmental management requirements. The improvements have come about amongst other things by the introduction of frame-work discharge permits, environmental testing requirements for chemicals, requirements on substitutes and the operator's follow up of the phasing out of potentially harmful chemical sub-stances. The chemicals on the Norwegian Pollution Control Authority's A and B[2] list (environmentally acceptable) increasingly make up a larger portion of the discharges (see figure 25).

Tools have been designed to ensure that the environmental improvements are achieved in the most efficient manner. CHARM (Chemical Hazard and Risk Model) is a method used to rank the environmental impact of chemicals. By using CHARM the industry can compare the different chemicals and choose the ones that have the least harmful effects. The authorities have also imposed on the players to carry out environmental risk assessments (by means of CHARM) of new chemicals being employed. A method called EIF (Environmental Impact Factor) has also been developed which makes it possible, on the basis of knowledge about discharged quantities, spreading and toxicity, to determine which components in produced water that are most harmful to the environment. The DREAM project (Dose-Related Risk and Effect Assessment Model) is another tool designed to limit the risk of harming the environment from the discharge of produced water. This latter is based on EU guidelines for environmental risk assessment.

> To date both the planning and execution of all the drilling operations in deep water have been successful.

[2] The chemicals are commonly divided into four classes (lists):
1. List A (PLONOR) are chemicals assumed to have a minor or no negative effect on the environment
2. List B contains chemicals that may have a temporary effect on the marine environment, but which are well documented.
3. Chemicals to be phased out.
4. Chemicals which have a discharge ban.

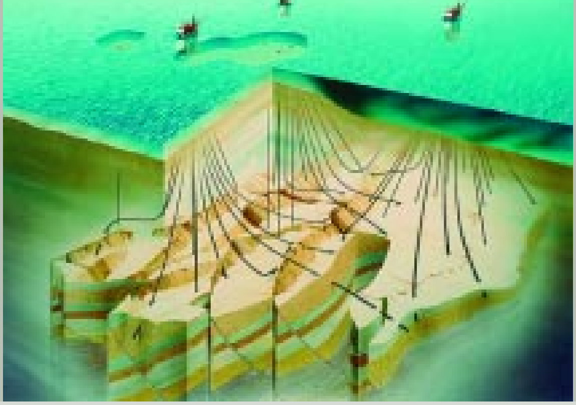


Figure 26 Technological developments within drilling and well operations. *(Source: Statoil)*

TECHNOLOGICAL SOLUTIONS

Drilling and well operations

Technological developments in recent years have contributed to improved mapping of reservoirs, which in turn has resulted in fewer dry holes. This has led to a considerable reduction in discharged quantities.

New drilling technology. In recent years the rapid development of drilling technology has led to major efficiency gains. By employing this new technology it is possible to drill very long and deviated wells, horizontal wells and wells which curve and bend. All of these come under the expanded term of directional drilling. The development of multilateral drilling will further reduce the need of wells by having more branch wells down in the reservoir, which share the upper part of the well. The combination of long, horizontal and multilateral wells has several environmental advantages. The reduction in the number of wells reduces the production of cuttings and drilling fluids, while at the same time reducing the use of chemicals. Another beneficial side-effect is reduced energy consumption. Larger areas can now be reached from one installation and reduce the pollution associated with development and operations (see figure 26).

Reinjection of oil-based drilling waste has now become a standard operational procedure on most fixed installations. In 1999 a total of 72% of the oil-based drilling waste was reinjected. The cuttings are ground up and diluted before being injected back to a formation by means of the mud injection pump.

Reuse of drilling fluids. Some companies have routines for re-circulation and regeneration of used drilling mud. Suppliers of drilling mud are continually working to improve such routines. Environmentally-friendly drilling fluids with good technical qualities are also increasingly being developed.

Alternative weight substances. During a drilling operation it is necessary to add a weight substance, usually barytes. This additive contains heavy metal which is not desirable for environmental reasons. Ilmenite is an alternative weight substance that contains less heavy metal and which is used on several installations in the Norwegian sector. Ilmenite opens up new areas of application for drill cuttings. Instead of depositing cuttings as special waste onshore, it can be used to cover pipelines, in the cement and ceramics industry, as a filler in asphalt and rubber and to surface cycle and walking paths.

Produced water

Steps to reduce the environmental damage caused by the discharge of produced water can be divided into four technological areas (see figure 27):

- Reduction of water production
- Reinjection of produced water
- Treatment of the produced water before discharging it to sea
- Reduced discharge of environmentally-harmful chemicals.

Water shut-off down in the wells is used to reduce the production of water and thus the discharge of produced water. Mechanical methods are most common to day. Chemical shut-off methods are less used amongst other things because they require

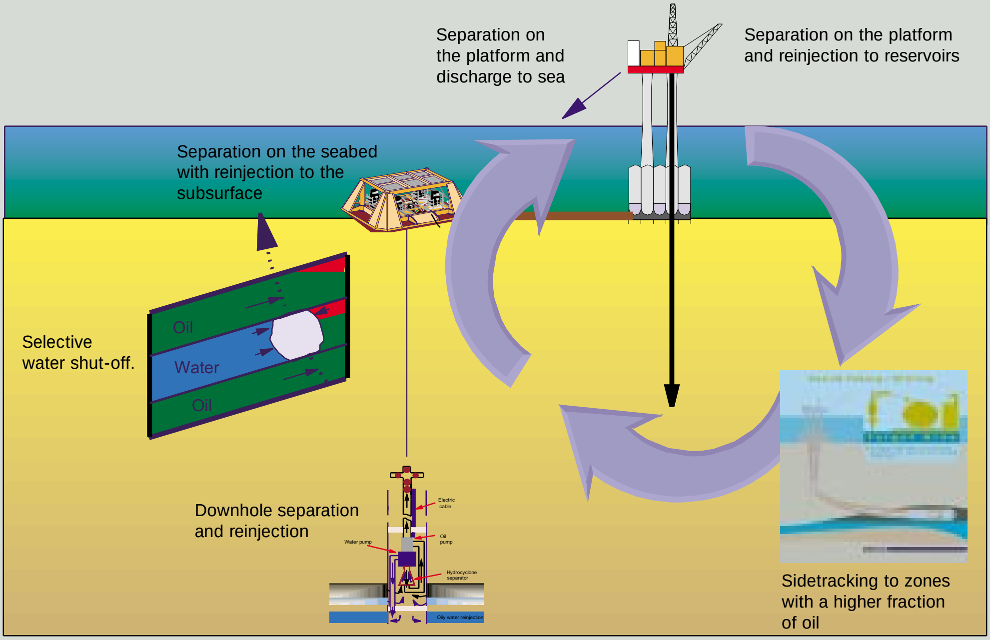


Figure 27 Technological solutions for the treatment of produced water. *(source: Statoil)*

Figure 27 illustrates different methods to reduce the production of water (water shut-off, downhole separation and sidetracking), as well as reinjection after separation on the platform and on the seabed.

Reducing water production. The best way of reducing discharges associated with produced water is to reduce the production of water. The shape and location of wells may affect how long it takes before the field begins to produce water and how much water that is produced.

special reservoir conditions to be successful and because problems of durability sometimes occur. Over the years new equipment and methods have provided a flexible and selective way of shutting-off of water-producing zones, which do not require the use of a drilling installation. The trend is towards equipment that can be remotely controlled from the surface.

Downhole separation. By using downhole separation the produced water is separated down in the well and reinjected. The main aim of downhole separation is to avoid handling large quantities of water on the installation by moving the process down into the production well. This also prevents the capacity of the processing system becoming a problem when the water production increases. This can help prolong a field's lifetime and so enhance the oil production. At the same time the use of chemicals is reduced because of improved separation conditions and by avoiding discharges through water reinjection. This process removes almost all of the water from the production flow.

Reinjection of produced water. The reinjection of produced water is an important option because it can do away with the discharge of oil and chemicals from produced water. However, this option is dependent on the specific reservoir conditions and it can therefore not be applied everywhere. If the decision is made early in the planning phase of a new field to reinject the produced water, then the extra costs of reinjection will be much lower than if it is implemented at a later stage. A decision to reinject produced water to provide pressure support and boost production may only marginally increase the investment costs of a new installation and cause no or a very limited increase in the emission to air. If the produced water for some reason cannot be used as pressure support and a separate injection well must be drilled this would mean considerable extra investments and an increase in the emission to air. On existing installations it may be possible to convert to reinjection without major outlays, if conditions allow it. In the Norwegian sector more than ten fields reinject produced water or have plans to do so, and this option is being considered at several other fields. It is expected that the amount of produced water that is reinjected will increase in the coming years.

Seabed separation. Seabed separation involves separating the produced water from the well flow at the seabed, so that only oil and gas are transported up to the production installation. This method will reduce the amount of water requiring treatment on the installation. The separated water is for the most part reinjected. Discharges at the seabed would only result in minor discharges of chemicals because of the reduced need of corrosion and hydrate inhibitors on the surface. In order that this technology is to become a real environmental alternative to downhole separation, the water must be reinjected and possibly provide pressure support at those fields where this is possible.

Treatment of produced water before discharge to sea. Treating or cleaning produced water is primarily done by removing the oil before the water is discharged to sea. Oil recovered in this way is fed back to the oil treatment facilities and sold together with ordinary crude. The removal of other substances, such as heavy metals, aromatic substances and phenols, may lead to end products that must be handled and deposited in an environmentally-safe manner.

The treatment of produced water on installations is done by means of physical facilities such as flotation tanks, separators, hydrocylones and centrifuges. Depending on the process chosen there will always be oil residues in the water. The discharge requirement of oil in the water is 40 mg per litre. The oil content in produced water varies considerably from field to field, but on average the concentration of oil in recent years has been stable around 22-25 mg per litre. But there is a rise in the total amount of oil discharged because of a higher production and discharge of water.

Different measures are being introduced to make the treatment process better, simpler and cheaper, while at the same time reducing the chemical requirements. To considerably enhance the effect of the treatment of oil and other components, several treatment stages utilising different technologies which operate in a series, may have to be built. There are a number of methods for further cleaning the produced water, but some of these require plants that are too cumbersome or complicated for use offshore. Some methods are being tested offshore, while others are being looked into to a varying degree. Among the most relevant treatment technologies for use offshore Norway are:

- Methods for making small drops of oil melt together into bigger drops so that the oil can more easily be separated from the water in the separation process. Varieties of this has been tested at the Draugen field and used at Troll.
- A method where the oil components are captured by the condensate, which is mixed with the produced water. This technology has been tested at the Statfjord field.
- Methods consisting of different types of filters which can remove oil and other components from the water. This technology has been tested at the Oseberg field.

Some of the treatment methods can also remove other organic components, particles, chemical residue and heavy metal from the produced water.

CHALLENGES

It is a challenge to reduce environmentally-harmful discharges to sea without this leading to a higher energy consumption and increased emissions to air. It is necessary to undertake an overall evaluation of the different measures, while at the same time taking into account conditions specific to the different fields. Good knowledge about the reservoir and hydrocarbon flow may make it possible to place wells in a manner that contributes to reducing the production of water. Process optimisation is another option requiring integration of know-how from different skills and operating environments. Several different technological options exist at the moment. But as several of these technologies have not been tested and undergone qualification, it remains a challenge to decide which method should be selected for a particular field. In this context cooperation and sharing lessons learnt could be very important in finding solutions based on cost/utility considerations. On many installations several smaller measures have been introduced which collectively can contribute considerably to discharge reductions. It could be very useful to share this knowledge and the lessons learnt.

For further information view the Internet pages of:
Norwegian Pollution Control Authority:
http://www.sft.no
Norwegian Oil Industry Association:
http://www.olf.no (Including the MILJØSOK-reports)
OSPAR: http://www.ospar.org

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