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Management and Treatment of Produced Water and Open Drain Wastewater in Azerbaijan Oil Industry

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Author's declaration

No portion of the work referred to in this thesis has been submitted in support of any application for another degree or qualification of this or any other university or other institute of learning.

Sabina HUSEYNOVA

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Abbreviations

ACG	Azeri-Chirag-Guneshli
AzSPU	Azerbaijan Strategic Performance Unit
BAT	Best AvailableTechnology
bbl	Barrel
bbl/d	Barrel per day
BOD	Biochemical Oxygen Demand
BP	British Petroleum
BTC	Baku-Tbilisi-Ceyhan Pipeline
CA	Central Azeri Platform
CWP	Compression and Water Injection platform
EBRD	European Bank for Reconstruction and Development
EIA	Environmental Impact Assessment
EMS	Environmental Management System
ESIA	Environmental and Social Impact Assessment
HSE	Health, Safety and Environment
MENR	Ministry of Environment and Natural Resources
MARPOL	International Convention for the Prevention of Pollution from Ships of 1973, as modified by the Protocol in 1978
μ	Microgram
Mg/l	Milligram per Liter
MPPE	Macro-porous Polymer Extract
NGO	Non Governmental Organization
PSA	Production Sharing Agreement
PW	Produced Water
SOCAR	State Oil Corporation of Azerbaijan Republic
ST	Sangachal Terminal
UN	United Nations
UNEP	United Nations Environmental Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
WMO	World Meteorological Organization
WB	World Bank

Glossary

Aromatic Hydrocarbon – hydrogen and carbon compound with the ring structure of six atoms

Azeri, Chirag, Guneshli – Oilfields on the Caspian Sea which are developed by the AIOC under the Production Sharing agreements

Azerbaijan Strategic Performance Unit (AzSPU) – BP business unit responsible for the operations in Azerbaijan. Performs under the direct supervision of the executive committee

Barrel – Traditional English and American measure of oil volume. Equals 159 liters ($0.159m^3$)

Biological Treatment – treatment option based on bacteria introduction for consumption of organic components

Bund – a wall which is built around the storage tank to contain its content in case of spillage

Crude Oil – natural not refined hydrocarbons

Corrosion Inhibitors – chemicals added to the product to delay the process of corrosion

Evaporation Pond – an option used for the disposal of produced water. Water evaporates naturally under the normal weather conditions.

Health, Safety and Environmental (HSE) Management System – structure, procedures, programs, processed used by the company for implementing HSE management system

Hydrocarbons – Natural compounds of carbon and hydrogen

Injection well – a well used to introduce water into the reservoir for its enhanced recovery

Pigging – a process when a gauge or a pig is sent through the pipeline for the pipeline inspection purposes. Used for pipeline integrity monitoring

Produced water – the by-product of oil and gas extraction, which naturally accompanies oil production

Re-use – the use of products that are re-usable in their original form

Salinity – total amount of salt content dissolved in the water solution.

Sangachal Terminal – a facility used by AzSPU for the receiving and preliminary processing of oil and gas from the offshore platform before their distribution to the designated points by the pipeline

Water Separation – the removal of water from the oil.

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ABSTRACT OF THE THESIS submitted by:

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Nowadays, the oil and gas industry encounter growing water related problems that threaten the development of the industry and its sustainable performance. The main reason of the risks associated with the wastewater is the increasing volumes of produced water and problems related to its discharge. Produced water is the largest waste stream if considered by volume. It contains high concentration or organic and inorganic components. Produced water can be one of the most considerable sources of negative impacts on the environment associated with the oil and gas industry. Currently the worldwide practice is to re-inject the produced water into the existing oil reservoirs, discharge to the natural waters or re-use in some technological processes.

Open drain water, is another wastewater stream related to oil and gas industry. The volumes of open-drain water cannot be compared with the produced water volumes, but the management and treatment of this wastewater stream also requires specific attention.

It is generally considered that oil industries have one of the largest negative impacts on the environment. This paper reviews how the existing technologies available for oil industries, management approaches and legislative framework can mitigate the environmental impacts of wastewater and ultimately contribute to the sustainability of oil industries.

Keywords: wastewater treatment, produced water, open drain water, Azerbaijan oil and gas industry, treatment technologies, integrated wastewater management approaches.

Chapter 1: Introduction, Aims and Objectives

1.1 Introduction and Background

There is a historical paradigm about oil and gas industry, based on the existence of great volume of wastewater, generated by them, that the companies working in this industry are not properly identifying, evaluating or managing the risks associated with water (Society of Petroleum Engineers 2008). There is a widely known concept that it is impossible for industry to co-exist happily with the environment as “the requirements of each are presumed to be mutually exclusive” (M.Kelly 1991).

Nowadays, the oil and gas industry encounter growing water related problems that threaten the development of the industry and its sustainable performance. The main reason of the risks associated with the wastewater is the increasing volumes of produced water and problems related to its discharge. At the same time scarcity of fresh water and access to clean water are critical issues that may affect economic activity and development in the world. Usually, the extraction processes take place in ecologically sensitive areas and with involvement of water-intensive processes that tend to generate huge amounts of wastewater.

The term *produced water*, or *co-produced* water, is defined as the by-product of oil and gas extraction (Benko and Drewes 2008). It contains high concentration or organic and inorganic components, due to the fact that the water is in the contact with hydrocarbons and geological formations by the time it is extracted to the surface. At the same time produced water generated by the oil & gas industry is characterized by different chemical and physical features, which are very variable depending on the geology of the oil and gas field and the geographical location and type of hydrocarbon being produced. In addition the characteristics of the produced water tend to change in the course of aging of the oil reservoir.

The oil and gas industry generated different wastewater streams, but this work will be primarily focused on produced water, based on the following reasons. Produced water is the largest waste stream if considered by volume. Some calculations state that annual worldwide water production by oil and gas industries is more that 77 billion-barrels. (Moritis 2007). It is ten times more than the volume of annual extraction of oil and gas (Benko and Drewes 2008). It is estimated that in most parts of the world, produced water rates will increase with time, mostly due to the aging of the wells (Dell *et all* 2008). At the same time the legislation related to its discharge is becoming more stringent. The new technologies and treatment strategies are to be implemented to deal with the problem effectively.

Consequently, produced water can be one of the most considerable sources of negative impacts on the environment associated with the oil and gas industry (Cakmacki et al. 2007). Due to specific characteristics it is very difficult to treat it. Currently the worldwide practice is to re-inject the produced water into the existing oil reservoirs, discharge to the natural waters or re-use in some technological processes. If not treated and managed properly produced water may negatively influence the environment. Due to its high salinity and chemical composition it can possibly contaminate the surface and underground waters and soil. This will ultimately affect oil and gas industry and companies involved in this business by legal responsibilities and reputation damage. Due to all those factors some oil and gas companies face the challenges of water risk evaluation, management and reduction.

In the lesser extent the current work will be focused *open-drain water,* which is another wastewater stream related to oil and gas industry. The term open-drain water can be defined as contaminated rainwater from the processing areas with potential oil and chemical content (BP ST 2007). The volumes of open-drain water cannot be compared with the produced water volumes, but the management and treatment of this wastewater stream also requires specific attention. Lack of this attention can also result in the environmental impacts related to the contamination of surface waters, if open-drain water is introduced into the main drainage system without treatment.

Azerbaijan has a long history of natural resources development and the oil and gas sectors are widely represented in the country. The Oil Industry is nowadays associated with many environmental problems, such as ecosystem damage, water pollution, soil contamination etc. For the purposes of this work two companies involved in the oil and gas industry in Azerbaijan have been chosen to conduct case studies – BP (British Petroleum) Exploration Caspian Sea Ltd. and State Oil Corporation of the Azerbaijan Republic (SOCAR). These companies have been selected due to the following reasons.

Exploration, exploitation, refining and transportation of oil resources are under the control of the State Oil Company of Azerbaijan Republic (SOCAR). SOCAR is involved in the onshore and offshore oil and gas extraction. It develops 78 onshore and offshore production fields in

Azerbaijan, most of them are quite old and produced water volumes are high (APS 2004). SOCAR has inherited the produced water contaminated land on the Apsheron peninsula from the historical Soviet times of intensive oil and gas extraction. These contaminated sites represent one of the main environmental concerns in the country. The rehabilitation of these lands and improvement of the ecological situation on the Caspian Sea are now the priorities for the company. Currently, SOCAR is planning massive clean-up operations of these produced water contaminated sites (SOCAR 2008).

One of the most prominent representatives of the oil sector in Azerbaijan is BP. BP came to Azerbaijan oil and gas industry in 1994 when "contact of the century" was signed between Azerbaijan and foreign investors. In the framework of this contract Azerbaijan Republic has signed the Production Sharing Agreements (PSA) with many international oil companies for development of more than 20 oil fields. BP operates a number of oil and gas projects in Azerbaijan and most of the activities are concentrated in offshore oil fields in the Azerbaijan sector of the Caspian Sea. The two principal development fields are Azeri-Chirag-Guneshli oil field (ACG) and Shah Deniz gas field. Offshore exploration operations are associated with significant environmental risks and this is the main environmental concern for the country. Wastewater treatment is one of the most crucial among these concerns and it is common for oil industries in many countries. ACG and Shah Deniz fields are generating produced water and as it is estimated by the Company that the peak of the produced water volume is expected around 2008 (BP 2006b)

The treatment of produced water for its discharge offshore has recently been researched internationally, especially in such countries as USA, UK, Kuwait, China, Turkey, where the extractive industries are intensively developing (Cakmakci *et al*. 2007; Benko and Drewes 2008; Hubail and Dash 2005; Ji *et al*. 2006). In Azerbaijan there are also some available studies on the produced water treatment but they are not well developed and systemized (Abilov 2005; Salimov 2007; URS 2002; ASOSRP Institute 2007).

There are different technologies used around the world for wastewater treatment. Such technologies as Reverse Osmosis, membrane methods, ion exchange methods, hydrocyclones, MPPE, filtration etc. are used to remove salts, oil and other chemicals. In some cases the different combinations of treatment are applied to remove the components of the wastewater. The technologies to wastewater treatment are reviewed by its applicability to the individual case as local requirement and standards for the treated water quality can differ from country to country.

The international experience for the produced water treatment is not always applicable to the Caspian Sea. In most places the discharges into the sea of wastewater are to certain extent allowed. The Caspian Sea, the largest lake on the earth, has unique hydrochemical and geological features. Due to this fact and in addition to the high level of pollution, caused by long history of offshore development, Law was adopted forbidding the discharges of any wastewater generated during the technological processes related to oil and gas exploration and extraction (Environmental Law 1992). This fact may affect the applicability of worldwide-developed technologies as not all of them can be applied to the produced water generated from the oil and gas extraction from the Caspian Sea region.

The present work focused on produced and open-drain wastewater helps to find answers on the existing wastewater related challenges the oil & gas industry encounters in Azerbaijan. It reveals the possibilities for mitigation of environmental impacts associated with the oil and gas industry related produced water and open drain water from the three perspectives: technological, managerial and legislative. The existing technologies worldwide for the treatment of produced and open drain water are reviewed and compared, with the analysis of their applicability to Azerbaijan produced water treatment. The existing legislative framework for the regulations of the management of produced water and open drain waters is reviewed as well. And finally the existing produced and open drain waters management aspect implemented by the two companies are researched upon. It is anticipated that the present work will contribute to the improving of treatment technology performance and development of a comprehensive view of the oil and gas industry wastewater in Azerbaijan.

1.2 Aims and Objectives

The current work aims to research the impacts of the Azerbaijan oil and gas industry-related wastewater on the environment and ways to overcome them. The main theoretical question around which the whole thesis is built the question of possible synergy between oil industries and sustainable development. It is generally considered that oil industries have one of the largest negative impacts on the environment. This paper reviews how the existing technologies available for oil industries, management approaches and legislative framework can mitigate the environmental impacts of wastewater and ultimately contribute to the sustainability of oil industries.

In this regard, the approach is chosen, which is based on the following aspects: environmental impacts related to the specific wastewater streams generated by oil and gas industry; existing technological solutions and possibilities for their improvement; compliance with the existing laws and regulations; integrated concepts of oil and gas wastewater management. This approach had been chosen due to the fact that it would help to see the full range of wastewater-related issues, main challenges and improvement potential in this area. The concentration on one of the before mentioned aspects would have not been able to provide the insight on the existing paradigm related to oil and gas wastewater.

The following types of wastewater were considered for the purposes of the current research: produced water and open drain water. Analyses were provided on the amount of wastewater generated, the volumes of water disposed and reused.

The research was carried on BP's technologies and implementation of company's wastewater management system in comparison with the existing technologies and management approaches used by SOCAR.

As a result of this study a series of short, medium and long-term recommendations are developed and justified. This forms the basis for a sustainable approach to the problem, which is vital for protecting the environment while keeping the oil industry alive.

Results of the research would help the Azerbaijan Oil Industry in its efforts to create sound wastewater management compliant with industry's best practice and international standards and regulations. This will be reached in the process of the research by achieving the following objectives:

- Review produced water management practices currently used by BP and SOCAR
- Review of technologies used by these two companies
- Evaluation of the produced water laws and regulations compliance by the companies
- Evaluation of wastewater management improvement options by introducing new and optimizing old technologies for dealing with wastewater

- Explore the possibility for the long term improvement for waste water management considering the potential to have an integrated end disposal point e.g. wetland
- Application of wastewater treatment and disposal options in Azerbaijan aligned with the experience of other countries and with due respect to sustainable approach to wastewater management issues

In this research the focus will be made on the integrated concepts in the management of wastewater. The main elements of these concepts are in sustainable approach to the problem of wastewater, its generation and disposal practices. Current trends existing in this field include new technologies for wastewater treatment, new practice for re-use of wastewater, support by regulation and changing global perceptions on the subject.

1.3 Thesis Structure

The following Chapter 2 *Oil and Wastewater*, provides the overview of the existing literature in the field of oil and gas industry wastewater. It covers the environmental impacts related to the oil and gas industry wastewater, wastewater streams generated by this industry, available treatment technologies and existing management approaches. Furthermore, it provides the overview of the Azerbaijan Oil and Gas Industry, provides information on the composition of the produced water and open drain water, and chemical composition of natural waters.

Chapter 3 discusses the *Methodology*, which was applied for the data collection and analysis. Chapter 4 provides overview of the existing *National and International Legislation* related to the produced water and open water treatment and management. Chapters 5 and 6 cover the *Case Studies* – BP Case Study and SOCAR Case Study. Chapter 7 represents the *Assessment of Produced Water and Open Drain Water treatment in Azerbaijan Oil and Gas Industry*. Chapter 8 provides short-term, medium-term and long-term Recommendations based on the outcomes of the work. The summary and main outcomes of the research are provided in Chapter 9.

Chapter 2: Oil and Wastewater

2.1 The Development of Oil Industry in Azerbaijan

The present chapters are based on the review of the existing literature in the field of oil industry and wastewater related to it. Due to the nature of the work the literature sources related to treatment processes and techniques were given special attention to. This Chapter deals with the review of literature in the following areas: history of the oil industry in Azerbaijan, environmental problems related to oil industry, wastewater composition and its impacts on the environment and existing technologies on wastewater treatment.

2.1.1 History of the Azerbaijan Oil Industry

Azerbaijan is historically known as region of rich natural resources. Oil was discovered in the region in the early 19^{th} century. Oil and gas industry development started in Azerbaijan in 1870s. Although some authors, citing Marco Polo, who reported even in 13^{th} century that oil from Absheron peninsula was exported to Middle East, have the idea that oil was discovered in this region earlier (Tsalik 2003).

Most oil reserves are concentrated on the Apsheron peninsula. This region is considered the oldest oil region in the former Soviet Union (Hassmann 1953). In 1848 one of the first oil wells in the world was drilled in Apsheron peninsula. (International Energy Agency 1998).

Not surprisingly the first oil pipeline in the region, originated from Baku, was constructed between 1889-1896 (Kleveman 2003). Transportation of oil to Europe was very important issue taking into account the disadvantages of Baku's geographical position, as it is landlocked by the Caspian Sea. Initially tankers were used to transport the oil by the Caspian Sea and then by train to destinations in Europe. It is worth mentioning in this respect Nobel Brothers Oil Extracting Partnership that was founded in 1873. The Nobels played an important role in the development of oil sector in the Caspian Sea. They first bought tankers, which organized a fleet, which increased transporting capacity over the Caspian Sea and made Baku "the busiest port in the world" (Karagiannis 2002).

Later, the solution was found to construct the oil pipeline for oil transportation purposes. It was seventy-kilometer-long, 8-inch line with the capacity of approximately one million tons of crude oil, which connected Baku and Batumi on the Black Sea. The new shipping routes increased oil market borders. Exactly with this period some authors associate the beginning the oil boom in Azerbaijan and competition between entrepreneurs such as Rockfeller, the Nobels and Rothschild (Hassmann 1953). Even after the collapse of the Soviet Union, notwithstanding the fact that the oil reserves in Azerbaijan are vast, the main problem that remained is the absence of routes to the Western Markets.

In 1916 Baku was producing 8 million tons of crude oil and was in the center of oil production during that period.

During World War II the Azerbaijan share in oil production constituted 70 percent compared with other oil regions of USSR. The oldest oil fields on the Apsheron peninsula are Sabunchi, Balakhany, Romany located north of Baku.

There were as well some advantages in the Apsheron peninsula oil development. The first advantage was the fact that the oil deposits were concentrated in small geographical range on the Apsheron peninsula and that was making the development and production easier. Another advantage was in the location of oil deposits on the upper subsoil so that less technical efforts were required to extract it. Oil "fountains" were known as the phenomenon caused by natural pressure from the reservoir (Karagiannis 2002).

Oil industry of Azerbaijan stepped to another level of its development after World War II, when the first oil platforms appeared on the coast of the Caspian Sea. The new technologies allowed further conquering the sea depth and opened new horizons for the oil extraction and market development. The geologists started discovering new deposits and industry was flourishing rapidly ignoring the environment of the Caspian Sea and coastline zones, degrading the biodiversity and contributing to air and water pollution (Kleveman 2003). As a result of over-exploitation of the oil fields during the Soviet time, the main deposits, which remained untouched, were concentrated in the offshore fields. But Soviet Oil Industry could not develop these deposits due to its weak technological base. As a result offshore deposits of oil were left nearly untouched and by SOCAR data count for 17.5 billion barrels (outside estimates state 3-12 billion barrels) (Karagiannis 2002). "Ironically, the Soviet decision to leave Azerbaijani and Central Asia energy in the ground now threatens Russia's pre-eminence in the Caspian" (Ebel and Menon 2000).

Although, there are the opposite views of different authors, suggesting that region's energy wealth is a bit exaggerated and relies mostly on "possible" reserves rather than "proven" (Ebel and Menon 2000). In accordance with IMF data (IMF 1990) Azerbaijan's oil production peak is expected by 2010 and decline to a quarter of peak production by 2024.

2.1.2 Overview of Oil and Gas Sector of Azerbaijan

Notwithstanding the long history of oil production Azerbaijan had little experience in management of oil revenues. The oil being the primary source of revenues dominate over all the other industry branches and caused their productivity decline. As a result by 2001 oil exports constitutes 91% of the total value of exports (Tsalik 2003). Management of hydrocarbon revenues becomes important issue for country's development and prosperity.

After the collapse of the Soviet Union the new era began in the oil history of this region, known as "second oil boom" (Tsalik 2003). Some authors call this period the "Great Game", involving many actors and unpredictable events. (Karagiannis 2002).

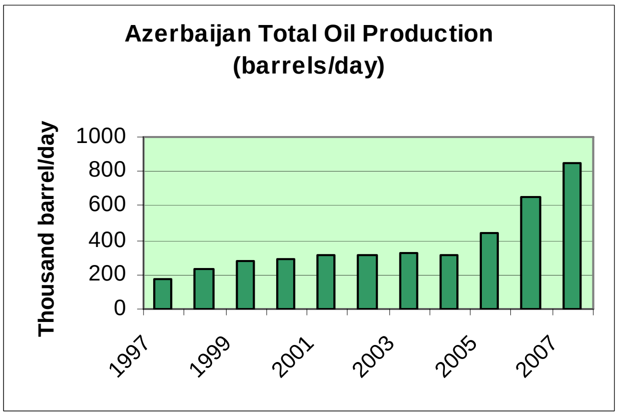
Foreign investors expressed their interest in the region attracted by the oil and gas reserves. The so-called "contract of the century" was signed in 1994 between Azerbaijan International Oil Corporation and foreign oil companies for the development of Azeri, Chirag, Guneshli offshore fields (Map 1), which opened the new perspectives for oil development. Azerbaijan in this respect made the steps to the creation of favorable climate for foreign investments by signing the production sharing agreements (International Energy Agency 1998). Investments into the oil sector considerably raised since that time and now represent 80% of total foreign investments (Tsalik 2003). The Azerbaijan Republic has signed over 21 Production Sharing Agreements (PSA) with international oil companies for development of more than 20 oil fields. BP was one of the companies having the shares in the "contact of the century" and project operator.

Now the main oil extraction, exploration, exploitation, refining and transportation of oil resources are under the control of the State Oil Company of Azerbaijan Republic (SOCAR). SOCAR was formed in 1992, based on the Ministry of Oil and Gas, by combining onshore and offshore operations on the Caspian Sea. SOCAR is the body responsible for negotiations with foreign investors and discussing and agreeing upon PSA. The mechanism of PSA is characterized as the system of "rendering to the Azerbaijani state its share of profit" and at the same time providing the foreign state with the opportunity "to recoup their investments"

(Hoffman 2000). The foreign participants of the PSA cover their costs in the beginning of production cycle, while the state will get the remained of the production shared by the schemes described in PSAs.

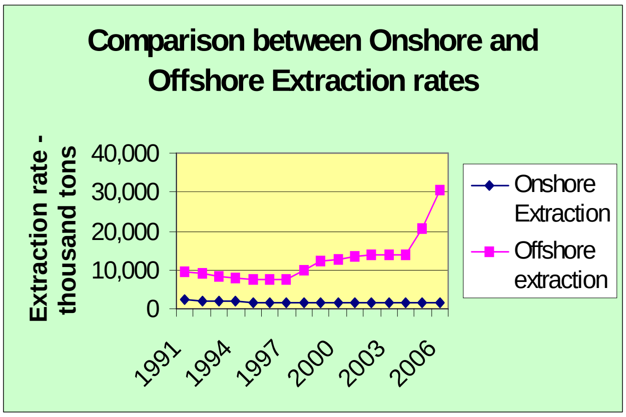
In 2007 in Azerbaijan oil production has reached about 860,000 bbl/d due to the development of ACG fields (EIA 2008) (Diagram 1). By the data of State Statistical Committee of the Azerbaijan Republic, during the period of 1991-2006 the oil extraction from offshore fields has increased from 9,504 thousand tons to 30,486 while onshore production has declined (Diagram 2). Gas production is limited if compared to oil. Shah-Deniz gas field is considered as the largest natural gas discovery for the recent period and contains from 25 to 39 trillion cubic feet of gas. Gas reserves in Azerbaijan are not considerable, counting for 0.5% of world total (IEA 2008).

Diagram 1: Azerbaijan Total Oil Production



Source: IEA
http://www.eia.doe.gov/emeu/cabs/Azerbaijan/Oil.html

Diagram 2: Onshore and Offshore extraction rates



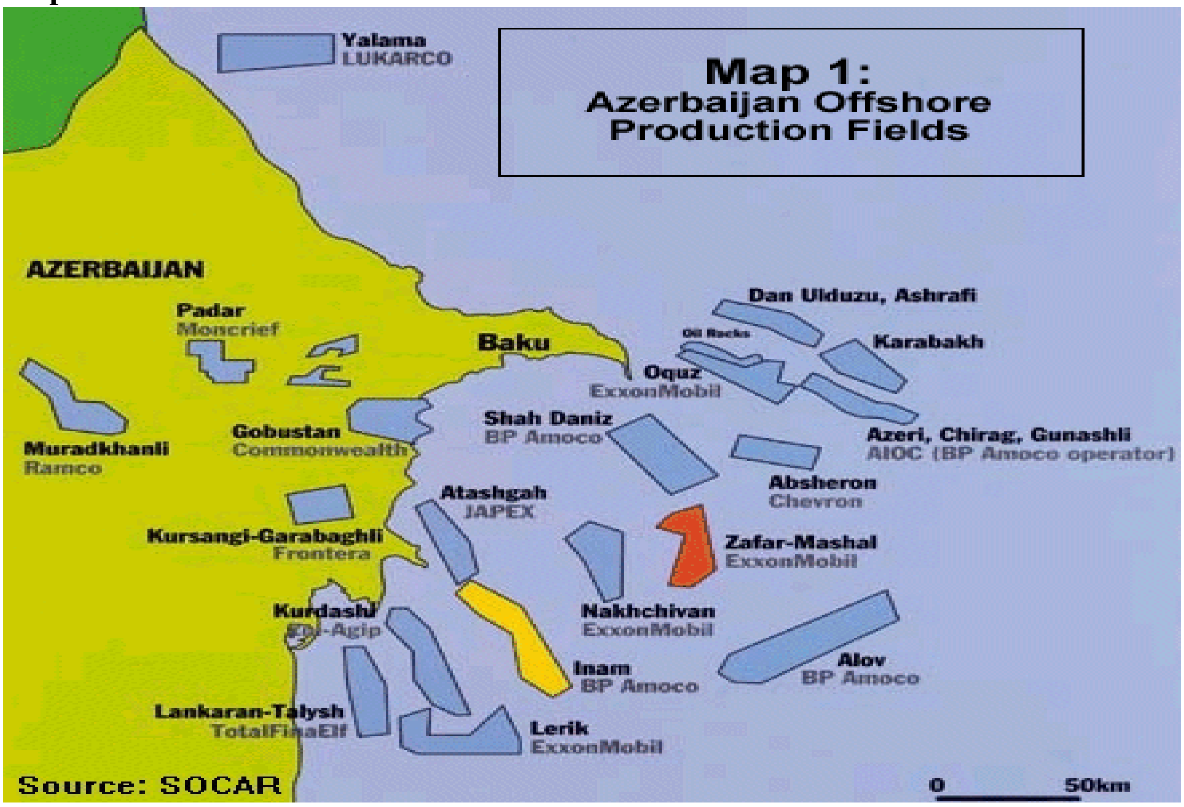
Source: State Statistical Committee of the Azerbaijan Republic

Except ACG some of the development projects on the Caspian Sea did not prove the expected results and some of the companies announced unsuccessful drilling results and some PSAs have been terminated. ExxonMobile and Lukoil after the test drilling announced the failure to find the expected hydrocarbon reserves in Zafar-Mashal and Yalama blocks (EIA 2008).

The "great game" and western investment into Caspian region oil development had political goals in addition to economic, such as for example, consolidation of independence of these former Soviet "oil" countries, reduction of their dependence on Russia and development of stability in this region (Ebel and Menon 2000). In other words "geopolitical realities are likely to play a large role" in many decisions on the development and investment in the oil industry and transportation of the oil to the world market. (Karagiannis 2002).

Currently most of the activities are concentrated in offshore oil fields in the Azerbaijan sector of the Caspian Sea. Offshore exploitation of the Caspian Sea started in 1949. And in 1997 there were 17 offshore production fields under 200-meter water depth (International Energy Agency 1998). The question of oil transportation became vital again and the capacity of existing two pipelines built in the middle of 20th century transporting Azerbaijani oil to Russia and Georgia was insufficient for the predicted oil production in 90s. In March 1993 the agreement was made between Azerbaijan and Turkey for the construction of crude oil pipeline, which is now transporting oil from Baku to Ceyhan port in Turkey. The pipeline with the total length of 1,730-km starts at Sangachal Terminal located 55 km from Baku and goes via Georgia to Ceyhan. This pipeline is recognized as the best choice for reaching world market, by most governments (Karagiannis 2002). At the same time economic rationale of the pipeline was continuously questioned. As the pipeline's capacity is more than the oil reserves of Azeri, Chirag, Guneshli can produce and probably will need participation from other reserves to make it commercially viable (Ebel and Menon 2000).

Map 1: Offshore Production Fields



Source: Energy Information Administration (EIA)
http://www.eia.doe.gov/emeu/cabs/Azerbaijan/Background.html

2.2 Composition and Structure of Natural Waters

In a water molecule the atoms of hydrogen and oxygen are joined together in a linkage that is called "covalent bond" (two hydrogen atoms and one oxygen atom – H_2O). To have the stable chemical structure each hydrogen atom requires one additional electron, while oxygen atom needs two additional electrons. The strong link between two atoms of hydrogen and one atom of oxygen is formed as a result of sharing electrons between them. This factor determines the highly stable structure of the molecule and is responsible for the unique characteristics of water. (Jolankai and Gayer 1997).

The aquatic systems include both biotic and abiotic elements and represent very complex mechanism. The natural waters contain anions (chloride, fluoride, sulphite etc), cations (ammonium, copper, iron zinc etc.), dissolved gases (free chlorine, ozone, nitric oxide, hydrogen sulfide, carbon dioxide), organic compounds, organometallic compounds (Crompton 1992; Crompton 2006; Jolankai and Gayer 1997).

Jolankai (Jolankai and Gayer 1997) suggests comprehensive subdivision of the water components into five classes:

- ✓ dissolved inorganic ions & compounds
- ✓ dissolved organic compounds
- ✓ particulate inorganic compounds
- ✓ particulate organic compounds
- ✓ dissolved gasses

In addition to the above mentioned components the water parameters such as temperature, pH, alkalinity, turbidity, hardness should also be considered while determining water quality. Temperature effects chemical, physical and biological processes in waters. With the increase of temperatures the solubility of some chemicals rises and it can influence the effect of the polluting substances on the environment. *pH* levels demonstrate the balance between acids and bases and is used as a measure of hydrogen ion concentration (pH is measured from 0 to 14). pH level at 7 index indicates neutral condition. *Alkalinity* indicates the capacity of water to neutralize the acid and is usually considered as a function of carbonates, bicarbonates, hydroxides and indicates their presence in waters. *Turbidity* is used as a measure of the suspended particles, which are kept in suspension by turbulent flow. The amount of silt, clay, organic matter in water may be the result of run-off, natural erosion etc. *Hardness* as a water parameter is determined by the presence of calcium and magnesium in water and is usually measured as equivalent of calcium carbonate.

Total Dissolved Solids indicate the amount of dissolved components in water. The chemical and physical properties of water can change under the influence of such solids dissolved in water.

2.2.1 Water Composition and Natural Chemistry of the Caspian Sea

The Caspian Sea is the largest salty lake on the planet, characterized by the special natural conditions and chemistry. The Caspian Sea has passed the period of isolation from the World Ocean about 10000 year ago (Tuzhilkin *et al.* 2005). Salt composition and concentration of principle ions in the Caspian Sea as compared with the World Ocean are demonstrated in Table 1.

Table 1: Concentration of principle ions

Ions:	**World Ocean**	**North part of the Caspian**	**South part of the Caspian**
Sodium + Potassium	10.94	1.62	3.25
Calcium	0.41	0.20	0.36
Magnesium	1.27	0.37	0.75
Chlorine	18.98	2.65	5.46
Sulfites	2.65	2.19	3.05
Bicarbonates	0.14	0.18	0.22
Total	34.45	7.21	13.09

Source: Tuzhilkin *et al*: The Handbook on Environmental Chemistry – 2005

The oxygen regime on the Caspian Sea varies from region to region. For example, in the Northern part of the Caspian Sea the vertical increments of the dissolved oxygen as well as salinity are relatively small during the whole year. On the Southern part during the year there is decrease tendency for the dissolved oxygen concentration. Overall, the oxygen regime of the Caspian Sea is subject to the serious variations due to the continuous natural and anthropogenic impacts. (Tuzhilkin et al. 2005).

Hydrocarbons represent most of the discharges to the Caspian Sea, with the dominance of calcium hydrocarbons. In the seawater the calcium hydrocarbons are transferred into carbonates, which constitute the water sediments.

The pH value of the Caspian Sea is greater if compared with the other regions of World Ocean and this is caused by the great contribution of the fluvial waters to the chemical composition of the Caspian Sea. Rivers are characterized by high concentration of anions of weak acids, for example, carbonic acid. pH level on the Caspian Sea is subject to the seasonal fluctuations, especially in its North part.

Hydrochemical regime of the Caspian Sea can be characterized by “spatial inhomogeneity and multiannual instability” that are the main distinctive features if compared with the World Ocean. In addition, the hydrochemical regime of the Caspian Sea was subject to significant variations over the past decades, which have caused the change in the chemical composition of its water and ultimately affected the biotic components of the sea (Tuzhilkin et al. 2005).

2.3 The Influence of Oil Production on the Environment

After the industrial revolution, the “athropogenic aggression to the environment” became more visible. Many problems related to the field of environment became the subject of great concern (Goldenberg 1996). Freshwater and marine ecosystems, atmosphere, terrestrial ecosystems have been affected by anthropogenic activities. Large-scale extractive activities, burning of fossil fuels have started to interfere into the hydrogeochemical cycles as a result causing the generation of new environmental problems (Bartram and Ballance 1996).

Consumption and production of energy creates a lot of by-products that can destroy or damage our environment. (Liu 1993). The recent growth of demand for oil and consequently the development of oil and gas production industry, and the complexity of wastes generated by it, creates “significant potential for impact on public health and environment” (Borup and Middlebrooks 1987). The most environmental problems related to oil and gas industry are related to its day-to-day operations.

Although some oil companies, proclaim the statement that “environmental protection is an integral part of running the business” – and are committed to the environmental protection, what is clearly defined in their policies and management plans, the generation of petrochemical wastes, spills during transportation, production pollution remain one of the most significant problems of oil industries. The summary of the main environmental problems related to the energy is provided in the Table 2 below.

Table 2: Main Energy-related Environmental Problems

Environmental Issue	Main Source of concern
Urban Air Pollution	Energy sources production and transportation
Acid Rain	Energy: fossil fuels burning
Ozone Depletion	Industry
Greenhouse warming and climate change	Energy: fossil fuels burning
Coastal and marine degradation	Energy production and transportation
Toxic chemicals and hazardous wastes	Industry, energy sources production

Source: Jose Goldemberg 1996 Energy, Environment & Development

The sea serves a sink for most liquid wastes. Most of these wastes are generated on shore and come to sea through drainage and discharges into watercourses and from the atmosphere. Shipping, offshore mining, oil production are another energy-related sources of marine pollution (Goldenberg 1996).

In the oil and gas industry there are great variety of different processes, which cause complex waste problems. During the production of oil and gas, much water, air pollutants and solid waste are generated (Borup and Middlebrooks 1987). Due to the oil composition wastes generated from the oil industry usually contain toxic substances. According to Goldenberg (Goldenberg 1996) oil that contributes to the pollution of marine ecosystems can be divided into five main categories:

- natural sources
- atmospheric pollution
- offshore production
- marine transportation
- runoff and industrial waste

Onshore as well as offshore oil production contributes greatly to the pollution of coastal waters of the Caspian Sea. As it is mentioned in the Caspian Oil and Gas report (International Energy Agency 1998), and confirmed by SOCAR data the environmental standards agreed with foreign companies are sometimes “less stringent than those that were applied, though not necessarily enforced, under Soviet-era legislation.”

Although the technologies used for oil extraction and development onshore and offshore are similar, as well as waste streams produced, in some literature authors divide the environmental impacts depending on the location of the oil development fields and specific problems arising from it. Consequently methods and technologies used to avoid the impacts are in most cases can be divided into offshore and onshore related.

The offshore development is consisting of the following phases each of which is associated with specific waste streams: exploration, construction, drilling, operations (Dunderdale 1990; Kelly 1991). During the **exploration phase** the wells are drilled from the mobile rigs and if the oil is discovered and extent of the field is determined the further phase commences. The main impacts in this case are related to drilling operations, which will be discussed in detail during the description of drilling phase.

During the **construction phase** the platforms are installed, which carry a drilling rig and production facilities. Pipelines are also laid to shore where oil is further directed to the specific streams. The impacts in this phase are mainly related to the disturbance of the seabed and sedimentation in the water column, especially during pipeline trenching operations. Also before the construction phase is completed the integrity of the pipeline is tested by hydrotesting method, which is pressure testing with water. The water usually contains some concentrations of anti-corrosion chemicals. The discharge of this water represents another impact on the environment. In some cases it is discharged into the sea, in others it is sent to shore and collected there for further discharge.

Another problem related to the construction of the platform in the sea is the pieces of the equipment that can fall overboard. This dropped debris can damage the fishnets.

Drilling phase can be characterized as the source of greatest impact on the environment, due to the specific nature of this activity. The discharge of rock cuttings from one average well can count from 500 to 1000 m^3. As it is mentioned in some materials the only practical disposal of this material is its discharge onto the sea-bed under the platform (Dunderdale 1990).

During the process of drilling a special fluid called "drilling mud" is circulated through the hole. This drilling mud functions as lubricant for bit, prevents fluids entering from the formation and removes cuttings. The drilling mud consists of solid and water components. Solid components are usually natural clays (bentonite, for example). Depending on the liquid components there are water-based muds (sea water as the component is used) or oil-based muds (emulsion of water in oil as the component is used). The usage of oil-based muds have more environmental impacts on the sea but in some case due to the geology of the rocks to be drilled it cannot be substituted by the water-based muds. There is another alternative to the two kinds of muds mentioned above. It is increasing of mud fluid ionic strength with the use of such chemicals as potassium chloride. The usage of this method depends on the well itself and cannot fully substitute the oil-based muds. All of this drilling muds has impact on the environment and the main difference between the mud types is the rate with which the recovery of components in the sea takes place. Oil-based muds will recover longer due to the slow biodegradation of the oil. Generally, the measures and tactics are taken to mitigate the impacts on the environment caused by drilling operations. Here such tactics can be mentioned, as washing of cuttings before discharge, or substitution of diesel for oil-based muds with the less toxic mineral oils, distilling the oil and so on (Dunderdale 1990).

During the operation phase, the impacts reduce and become more related to the handling of oil and gas. Here can be mentioned flare gases, but most part of the gas is used as fuel on platforms. In some cases it is more feasible to transport this gas ashore.
With time the oilfields produce water together with oil and the proportion of water produced increases with time. There exist different methods to separate this water from the oil. The discharge mechanisms are also different. In some cases it is allowed to discharge produced water to the sea after treatment, in others the produced water is sent ashore for further treatment as on the platform this water cannot get the proper treatment due to limited space and capacity. The method for separation of oil from water is a combination of physical and chemical processes. In more details the technology of oil and water separation will be discussed in the next chapter.

The offshore oil development phases mentioned earlier are characteristics for onshore development as well. Almost the same technologies are used for drilling and production, but due to the geology onshore technologies do not require the usage of oil-based muds and that make the environmental impacts of onshore drilling activities less serious.

2.3.1 Water Pollution and Water Quality in Azerbaijan

There are a lot of sources of pollution in Azerbaijan. Water, air, soil are considerably contaminated and oil and gas industries are one of the causes of the situation (Robinson n.d). In accordance with the Azerbaijan National Environmental Action Plan (NEAP 2005) industry "has been a source of severe air, water and soil pollution for decades".

In accordance with the National Environmental Action Plan (NEAP 2005) the level of pollution at the Caspian Sea especially Baku Bay is extremely high, with the concentrations of hydrocarbons and phenols 10-30 times the Maximum Permissible Concentration levels. More than 60 million m^3 of sediment composed of up to 40% oil compounds have accumulated in Baku Bay. The levels of phenols and mercury are also very high. The population of sturgeon and other fish feeding mostly on benthic fauna in shallow areas are dramatically affected by this pollution. Baku Bay is also can be characterized by the low levels of oxygen, 1.8-3.0 mg/l (10 mg/l is a characteristic of healthy biological system). The data available for the pollution level on the South Caspian generally comes from the Azerbaijan Academy of Science and some monitoring reports. In accordance with Alexander Korshenko (Korshenko and Gul 2005) the waters of the Azerbaijan part of the Caspian Sea, especially Neft Dashlary (Oily Rocks) and Baku Bay, are considered as heavily polluted with the concentration of petroleum hydrocarbons (1332-1364 mg/l), detergents and phenols. The maximum concentration of petroleum hydrocarbon content is found near with the oil and gas extraction fields. The bottom sediments are polluted as well. They are dark-grey or even black in color and represent the mixture of crude oil, mud, detritus with shell. In Baku Bay the concentration of petroleum hydrocarbon sediment reached 95.1 mg/g and in accordance with this data the Baku Bay is the most polluted with petroleum hydrocarbon sediment part of the whole Caspian Sea (Korshenko and Gul 2005). In addition to the pollution by petroleum hydrocarbons the level of heavy metals concentration is also high.

The potential sources of pollution can be oil products, drilling muds, produced water, chemical reagents and so on. The discharge of these oil and gas production wastes into the sea was forbidden by the national legislation (Environmental Law 1982; 1984). There was a regulation introduced in accordance with which these wastes should be transferred to the shore and treated, discharged or re-used there.

Picture 1: Produced water discharges into environment, SOCAR onshore production site

Source: National Environmental Action Plan - 1996

Produced and process water from local oil and gas industries is sometimes mixed with sewage waters and discharged via the same piping infrastructure. Some of the produced and process waters are treated before discharge but treatment plants are old, and working not in a full capacity, requiring considerable improvements and refurbishment. Daily about one million m^3 of industrial wastewater is discharged directly to the Caspian without treatment. (National Environmental Action Plan 2005).

In Baku 50% of the sewage undergoes the process of treatment. The total daily discharge of wastewater to the Caspian Sea in Baku is 1.3-1.4 million m^3. From which about 30.000 m^3 of is untreated municipal sewage (NEAP 2005).

Generally, wastewater from offshore fields discharged into the sea are intended for dilution and decay, as the processes to prevent deterioration of the aquatic. The discharges from offshore platforms into the large water bodies such as seas were acceptable due to the fact that these water bodies were recognized as the “infinite sinks”. The example of the North Sea can illustrate quite clearly that during the decades of the offshore oil production and exploration the level of toxic organic chemicals, heavy metals and pathogenic organisms exceed the limits in many instances (Harsham 1995). The data above can prove that the same is true about the Caspian Sea. As a result the need to treat wastewater before the discharge into the aquatic environment to prevent the impact to the environment was recognized and specific regulations were adopted. Depending on the waste streams and applicable standards the different methods and technologies exist in oil industry to deal with the wastes.

2.4 Wastewater Streams in Oil Industry

Water is widely used by oil and gas companies around the World in their upstream and downstream operations. The multiple role of water in this industry can be summarized as follows (Dell *et al* 2008):

- Input to drilling activities as a component of drilling muds (the process described in previous chapter – drilling operations description)
- Testing tool for pipeline operations
- By-product from oil and gas production
- By-product of oil refining and gas processing
- Input to oil production operation
- Input to oil refining and gad processing operations

According to IFC Environmental, Health and Safety Guidelines for Offshore and Onshore Oil and Gas Development (2007) and Borup and Middlebrooks (1987) the wastewater streams can be categorized into the following main components:

1. Produced Water – formation water that present at oil and gas wells and becomes a by-product of hydrocarbon production activity. Gas reservoirs usually produce less by-product water if compared with oil reservoirs. Produced water stream can be considered as one of the main waste products of oil and gas industry.
2. Hydrostatic Testing Water – is used for verifying pipeline integrity by pressure testing with water.
3. Utility operations from energy production, cooling and heating systems
4. Sanitary sewage from administrative buildings and other facilities
5. Drainage and storm waters – generated from production units during normal operations. It worth mentioning, that closed drain systems are used for drainage waters from process area, that can be contaminated, while open drain systems for the wastewater from non-process areas.
6. General Oily waters – from drip trays from pipelines and equipment that should go to the closed drainage system
7. Wash waters from equipment and vehicles, should go to the closed-drain systems
8. Tank Bottom Waters is the rainwater infiltration through the tank roofs and accumulated in the bottom. These waters are usually treated together with produced water or as hazardous waste.
9. Miscellaneous discharges such as spills, firewater, turnarounds etc.

Offshore specific wastewater can be characterized like follows:

1. Desalination Brine
2. Bilge waters – usually comes from machinery spaces and support vessels

The streams of wastewater generated during oil and gas production are numerous and all of them cannot be covered in the current work. For the purposed of this particular research, produced water and open-drain water will be discussed and studied, due to the considerable volumes of these streams generated and significance of the impacts on the environment they may cause.

2.4.1 Produced Water Characteristics

Produced water is the water co-produced with the oil and gas. The term co-produced water denotes the water that is extracted from the subsurface geological formations, containing oil and gas. In general produced water contains formation water, injection water and condensed water. (Dell *et al* 2008).

As it was discussed in the Chapter 4.5 during the production there are a lot of unfavorable effects caused by the extraction activities. Produced water is one of the most important sources of these impacts on the environment (Cakmakci *et al*. 2007). Produce water constitutes 70% of all the wastewater generated during oil production. In some cases, depending on the age of the well, and some other factors, the volumes of the produced water seven or eight time more than the oil produced at some particular oilfields (Cakmakci *et al*. 2007).

Usually 65% of the produced water is re-injected into the well for the pressure maintenance. The rest 30% is injected into the deeper well. The remaining 5 % of the produced water have to be treated properly before discharge or re-use (Cakmakci *et al*. 2007). There are potential methods for produced water re-use, which will be described in the next chapters.

To determine and suggest any technology for the produced water treatment, initially it is reasonable to understand the chemical composition of produced water. Produced water contains inorganic and organic components. It includes salts and oil hydrocarbons that may be toxic to the environment (Cakmakci *et al*. 2007). Geographic location and geological formation of the production well determine inorganic composition of produced water. Organic composition depends on the type of the hydrocarbon produced and exists in two forms: "suspended dissolved oil drops, and dissolved organic compound". (Stephensen 1992, cited in Benko and Drewes 2008). Usually water and hydrocarbon components are immiscible, but various soluble components will dissolve in water phase (aromatics, for example). Different hydrocarbon compounds have different solubility in waters, usually aromatic hydrocarbons more soluble if compared with aliphatic hydrocarbons. Therefore in addition to suspended dissolved oil drops, produced water also contains small dissolved hydrocarbon component (aromatic hydrocarbons, organic acids and phenols) (OGP Report 2002). Some quantities of immiscible hydrocarbons (usually aliphatics) in the form of drops ranging in size from 1μm to 10 μm will as well constitute the separated water phase. In addition to organic and inorganic components produced water also may contain traces of chemicals added to production or separation processes. These chemicals are usually called “anthropogenic” chemicals (Norwegian Oil Industry Association 2003) and when component-specific data is not available, the amount of total chemical component in the water is used to determine water composition. In the category of anthropogenic chemicals the following compound can be listed: anti foam, corrosion inhibitor, scale inhibitor, emulsion breaker, biocide, H_2S scavenger. If representative compound for the chemical is chosen, the same compound is taken to represent biological and physical/chemical properties. (Norwegian Oil Industry Association 2003).

Overall, all the components that are contained in produced water can be commonly categorized into five main groups: aromatic components, aliphatic components, metals, organic acids and production chemicals (Dell *et al* 2008).

In some manual (OGP Report 2002; Dell *et al.* 2008) aromatic components are categorized into 3 groups:

BTEX: *Benzene-Toluene-Ethylbenzene-Xylene*
PAH: *Polyaromatic Hydrocarbons* (polycyclic aromatic compounds)
NPD: *naphthalene and phenanthrene and dibenzothiophene*.

The quality and composition of the produced water can differ from well to well and is always complex (Cakmakci *et al*. 2007; Benko and Drewes 2008). Produced water from oil and gas production has different characteristics and quantities. Produced water from gas production reservoirs is smaller is compared with oil production ones. If for example, the average gas field produces about 10$m^3$of produced water per day, oil fields generally produce hundreds or thousands of m^3 of water per day. (OGP report 2002). About the difference in composition between oil and gas fields, as per the same report, produced water from gas production fields contains higher concentration of “low molecular weight aromatic hydrocarbons” (benzene, toluene, ethylbenzene, xylene).

In addition, the composition of produced water also slightly changes during the production lifetime of the well (OGP Report 2002). At the beginning, oil or gas wells produce low quantity of water. This water appears after the process of condensation in the well, due to pressure decrease between downhole and surface. With aging of the well, the production of water increases. But composition of produced water remains the same. The composition may change only in case when the water injection is used for example for pressure maintenance and if this water reaches the well. In this circumstance the proportion of water compared with oil or gas changes, and the potential for additional dissolution of aromatics is being created.

Due to complex nature of produced water it is difficult to predict the actual quantity and composition in each stream. Produced water is generally characterized as “brackish groundwater with elevated concentrations of total dissolved solids (TDS)” (Benko and Drewes 2008).

For the purposes of this research project the typical data of Caspian Sea specific produced water composition was provided by BP Caspian Sea (URS 2002) (Table 3). The figures used in the Table below are not the actual values but the typical amounts:

Table 3: Common Inorganic Constituents in Produced Water

Composition	Produced water
pH	6.7-7.7
Oil (mg/l)	100-1,000
BOD5 (mg/l)	340
TSS (mg/l)	400
COD (mg/l)	700
Phenols (mg/l)	50
Cadmium (μg/l)	50
Chromium (μg/l)	100
Copper (μg/l)	800
Lead (μg/l)	500
Mercury (μg/l)	3
Nickel (μg/l)	900
Silver (μg/l)	80
Zinc (μg/l)	1,000
Chloride (mg/l)	10,900
Sodium (mg/l)	8,160
TDS (mg/l)	21,400

In addition to the above mentioned components, such production chemicals as scale inhibitor (10 mg/l), corrosion inhibitor (4mg/l), demulsifier (10mg/l) and methanol (1mg/l) may be contained in the produced water.

In contrast with the inorganic components of the produced water, organic components depending on such factors as age of the well, hydrocarbon product water in contact with etc, is more difficult to determine. For the purposes of this work, the organic components of the produced water given in Table 4 are provided without reference to the age of the well and product extracted and gives common organic composition of produced water from oil and gas extraction processes.

Table 4: Common Organic Constituents of Produced Water

Constituent	Low	High
TOC (mg/l)	NA	1,700
TSS (mg/l)	1.2	1,000
Total Volatile Organic (mg/l)	0.39	35
Total Polar compounds (mg/l)	9.7	600
Volatile Fatty Acids (mg/l)	2	4,900
Total recoverable Oil and Grease (mg/l)	6.90	210.0
2-Butanone (mg/l)	NA	0.37
Benzene	NA	27
Benzoic Acid	NA	13.5
Bis (2-chlorethyl) ether (mg/l)	NA	0.03
Ethyl Benzene (mg/l)	NA	19
Hexanoic Acid (mg/l)	NA	3.43
Methylen Chloride (mg/l)	1.41	1.17
m-xylene (mg/l)	0.015	0.611
Naphthalene (mg/l)	NA	0.556
N-decane (mg/l)	NA	0.797
N-dodecane (mg/l)	NA	2.89
N-hexadecane	NA	1.11
N-octadecane (mg/l)	NA	0.246
N-tetradecane (mg/l)	NA	0.404
p-cresol (mg/l)	NA	0.541
Phenol (mg/l)	0.009	23
Toluene (mg/l)	NA	37

Source: (Benko & Drewes 2008).

Understanding of the chemical composition of produced water is important as it gives an idea which treatment methods can be applied for different types of produced water. The majority of produced water contains homogeneous composition of major ions such as sodium, chloride, and sulfate. The existing and widely used desalination technologies can be applied for this water treatment. However, produced water from some wells may very high TDS concentration that makes its treatment for beneficial use not feasible. In this case the other option for disposal have to be investigated.

In the Norwegian Oil Industry Association (2003) Manual for Standardized Modeling and Determination of the Environmental Impact Factor Guidelines the composition of produced water was generally divided into the several main groups (Table 5). The physical/chemical and biological properties of some groups are represented by one compound, for some other groups by different compounds.

Table 5: Group of the main components in the Produced Water

#	Main Group	Compound	Physical/Chemical rep.	Biological rep.
1	*BTEX*	*Benzene-Toluene-Ethylbenzene-Xylene*	*Ethylbenzene*	*Benzene*
2	*Naphthalenes*	*Naphthalenes + C1-C3 alkyl homologues*	*Naphthalene*	*Naphthalene*
3	*PAH 2-3 ring*	*EPA 16 PAH*[1] *with 2-3 rings, Including C1-C3 alkylhomologues of phenanthrene and dibenzothiophene, excluding naphthalenes*	*phenanthrene*	*phenanthrene*
4	*PAH 4-5 rings*	*Coumpounds of EPA 16 PAH with 4-5 rings or more*	*Chrysene*	*Benzo(a)pyrene*
5	*Phenols C0-C3*	*Phenol +C1-C3 alkyl-homologues*	*p-Cresol*	*phenol*
6	*Phenols C4-C5*	*C4-C5 alkylphenol homologues*	*pentylphenol*	
7	*Phenols C6-C9*	*C6-C9 alkylphenol homologues*	*Nonylphenol*	*Nonylphenol*
8	*Hepthane*	*Aliphatic hydrocarbons*	*Hepthane*	*Hepthane*
9	*Copper*	*Cu*	*Cu*	*Cu*
10	*Zinc*	*Zn*	*Zn*	*Zn*
11	*Nickel*	*Ni*	*Ni*	*Ni*
12	*Lead*	*Pb*	*Pb*	*Pb*
13	*Cadmium*	*Cd*	*Cd*	*Cd*
14	*Mercury*	*Hg*	*Hg*	*Hg*

Source: **The Norwegian Oil Industry Association (2003)**

The problem of produced water and its discharge has been the main topic of discussion of OSPAR Commission. Of particular importance to the industry, OSPAR Recommendation 2001/1 aims "to prevent and eliminate pollution by oil and other substances caused by discharge of produced waster into the sea", ultimately required that no harmful substances are discharged to sea after 2020. (OSPAR 2001). Since that the Commission have regularly been discussing the questions related to the management of produced water such as treatment technologies, sampling, types of produced water composition and so on.

2.4.2 Open Drains Water Characteristics

For the purposes of this work the system of open drains can be characterized as follows: the open drain system is used to collect wash water and storm water run-off from oil production areas, which potentially can contain oil or other type of contamination. The drainage system can be of two types: surface or subsurface (FAO 2005). In subsurface drainage system the two types of drains are recognized: open drains and piped drains. Usually the open drains have the

[1] 16 EPA PAH compounds include: naphthalene, phenanthrene, acenaphthylene, acenaphthene, fuorene, antracene, fluoranthene, pyrene, benzanthracene, chrysene, benzofluoranthene, benzopyrene, indeno (1,2,3-c,d)pyrene, dibenz(a,h) anthracene, benzo(g,h,i) perylene

same functions as piped drains. The difference is in their construction. In the piped system the pipe itself is buries underground. While in open drain series the drains are installed in paved or the areas where utility equipment is located, and from these drains the water goes to the catchment basin. From the Catchment Basin the Open Drains are collected in the Area Sumps from where this water is transferred to the Holding Tank (European Commission Directorate General Joint Research Center 2001**).**

One of the components of the integrated wastewater management system in oil and gas production is the proper water and drainage system to cope with such circumstances as heavy rains or process failure. The separation and treatment of the potentially contaminated water from these drains then should be considered. Due to the hazardous nature of oily contaminated waters, the water management of these areas requires constant monitoring, analysis and alertness on the potential contamination (European Commission Directorate General Joint Research Center 2001).

The composition of open drain water depends on source of the contaminants and frequency of rain. It can contain oil or diesel from process areas, produced water and chemicals used at the facility, which can come from the spills or from the chemicals storage areas. Depending on the composition of open drain waters the appropriate technologies are used for its treatment.

2.4.3 Water Quality Monitoring and Water Sampling

The term "water quality" is the general description of the water composition as affected by nature and anthropogenic factors, expressed in measurable quantities and narrative statements (Novotny 2003).

In many countries there is a practice to set a limits on the discharges of hazardous water pollutants into the aquatic environments. Water quality criteria are developed by scientists and represent the information about the main effects of different pollutants on the water bodies and their consequent use (Helmer and Hespanhol 1997). For each intended use of water resources there may be different parameters determining water quality (Novotny 2003). So, the water quality parameters should be defined in terms of the "suitability for purpose" (Bartram and Ballance 1996). For example, the parameters for quality and the constituents of drinking water and water used for irrigation will be characterized by different requirements.

Monitoring can be interpreted as the continuous observation of quality determining the variables based on the standardized methodology with the further use of this information in quality control program (Jolankai and Gayer 1997).

"A criterion is a scientific quantity upon which a judgement is based, which is usually developed from scientific experiments and observations" (Novotny 2003). Water quality criteria are usually used as the baseline for determining water quality objectives. Water quality criteria have been established for such water variables as pH, biochemical oxygen demand (BOD), dissolved oxygen, chemical oxygen demand (COD), nutrients etc.

The water quality and pollution of watercourse is measured by the integrity of the following factors: chemical, biological and physical. Biological factors are determined by the fact that the surface waters provide habitat to different species and the level of pollution in the water can affect the abundance and distribution of these species within the habitat. Some species are tolerant to the different levels of pollution, others are diminishing as a result. For that reason the biological indices are widely used as a criteria for determination of the pollution level of the aquatic systems.
Hydrology, tidal effects, geographical location, geomorphologic characteristics are the criteria for the assessment of the physical factors affecting the integrity of the water body. (Novotny 2003).

The "anthropogenic" chemicals occurring in the environment can be characterized as the substances, which appear in the environment through the anthropogenic activity and their existence in large amounts can be harmful to living organisms (Jolankai and Gayer 1997). The chemical pollutants can be characterized as natural and synthetic (Jolankai and Gayer 1997; Novotny 2003). The natural or organic chemical pollutants are compounds containing organic carbon. While to the category of synthetic or inorganic pollutants belong pH, solids, salts, ions and colloids (Novotny 2003). In assessing the quality of the water the integrated chemical, biological and physical approach is implemented, which is usually result in integrated monitoring program (Novotny 2003).

For the setting and maintenance of the water quality objectives the monitoring programs, laboratory analysis schemes and surveillance mechanisms are to be in place. (Helmer and Hespanhol 1997). The monitoring is conducted to verify the quality of the water for its intended use or for discharge into the environment. There is another type of water monitoring intended to determine the impacts caused by pollutants on the aquatic environment. This type of monitoring is known as impact monitoring (Bartram and Ballance 1996). Like all the other types of monitoring, water quality monitoring should have clear objectives. While setting the objectives the following aspect should be considered: the purpose of conducting monitoring, what parameters should be checked, people responsible for different stages of monitoring, the intention of the further using of the information collected.

Sampling is the most important component of the monitoring process. The sampling process consists of different elements with the main objectives to define the concentration of polluting substances before the discharge to the aquatic systems or at the point of discharge and the determinations of such components concentration in the pre-mix environment (Harsham 1995). In some cases the results of sampling should be demonstrated to the appropriate bodies responsible for the discharge authorization. In this case, the requirements for sampling and its frequency are described in the compliance monitoring procedure. (Harsham 1995). To decide correctly on the sampling frequency the understanding on the variation in the concentration of polluting substances with time should be developed. In this respect Keith D. Harsham (Harsham 1995) in his recommendations advises to look at the both factors:

- the distance from the discharge point
- systematic as well as random/cyclic variations

If the sampling results demonstrate that the variation of polluting substances in water bodies is random, then the time of sampling should not play an important role. Otherwise, if the results prove systematic or cyclic variations then the sampling time should be carefully chosen.

The procedure to determine the presence of oils in the water samples, according to Crompton (Cromptom 1992) can be divided into 3 stages:

1. separation of hydrocarbons from the sample
2. identification of the petroleum product (crude oil, petroleum, gas oil etc)
3. identification of the pollution source

The physical methods of sampling can be subdivided into two main groups: manual and automatic sampling. The manual sampling is comparatively easy techniques when the container or tubes with remote lid are used, which are filled with water.

Automatic sampling is usually performed by micro-chip controlled systems with vacuum pump extraction.

2.5 Best Available Treatment Technologies

This Section will present the available technologies for the wastewater treatment particularly for the produced water and contaminated run-off.

The extent of treatment process usually defines the quality of the treated water. If the wastewater passed the processes of primary, secondary and tertiary treatment the quality of the effluent will considerably differ from the effluent, which only passed the process of screening. As a result the discharge of the wastewater after the process of screening required more consideration of the environmental impacts.

2.5.1 Main Aspects of the Treatment Technologies

The main stage of produced water treatment is based on the gravity separation of oil from water. Stroke's Law describes process of gravity separation. Different equipment is used to perform this process. Filtration or barrier separation are the other processes employed for the treatment of produced water. The equipment operating on the gravity separation principle will not be able to remove dissolved oil from the produced water. The dissolved oil typically presents at all the types of produced water ranging from 5 to 30 mg/l. To remove the dissolved oil the filtration method or membrane methods are used. In case when flow rates are high, the biological treatment method can be used, but it is not suitable for offshore installations.

The treatment process typically can be divided into four different stages: primary treatment, first stage treatment, second stage treatment, tertiary treatment. (Canadian Association of Petroleum Producers Report 2001) The primary treatment is directed at the removal of water from oil and gas. It is based on the gravity separation process. After the primary treatment process the oil concentration in produced water will in the range of 100-2,000 mg/l. After the primary treatment the wastewater goes to the treatment stages. The treatment system chosen depends on the characteristics of wastewater, available technology and regulatory standards.

Gravity separator is the simplest method of oil industry wastewater treatment. Vessel with enough capacity can be used where produced water is retained to allow water and oil to separate.

Parallel plate separators consisting of tilted parallel plates, gas flotation, hydrocyclones are also used for separation processes. The plates are arranged in a way that oil droplets are passing through the plates only need to rise a short distance before adjusting to the underside of the plate. This treatment method cannot remove the emulsions from the produced water due to the fact the oil drops in such emulsions are small in size.

Gas flotation treatment technology uses gas bubbles, which acquire small electronic charge opposite to that of the oil droplets. Oil droplets are attaching to the gas bubbles and as a result a gas and oil are driven to the surface. (Canadian Association of Petroleum producers Report 2001).

The methods described here only remove the oil from the water in the process of treatment. Treatment of the dissolved hydrocarbons such using membranes, biological treatment are described in the sections to follow.

2.5.2 Bioremediation of Metals and Hydrocarbons

Bioremediation is very old technology developed in 1972. This method was used for the spills cleaning from terrestrial and aquatic environments. Microbiological and engineering aspects are widely implied by these technologies. Microbiology plays an important role in understanding the processes being the cornerstone of the technology, while engineering systems provide necessary conditions to support the process of bioremediation. (Hinchee *et al*. 1994).

Due to that fact that the majority of the hydrocarbons in the composition of crude oil are biodegradable substances and the bacteria responsible for biodegradation of these substances are ubiquitous this method can be effectively used for the treatment of oily water. Electron acceptors, such as oxygen or nutrients such as nitrogen and phosphorus are used to alleviate the limitations of the microbial metabolism (Prince 2007). Nitrates can be used as an alternative electronic acceptor for the processes of anaerobic bioremediation (Hinchee etc al. 1994).

The experiments made by Texas Research Institute provided evidence that hydrogen peroxide can be used by hydrogen-degrading bacteria as a source of oxygen. The bioremediation using the hydrogen peroxide is used as in situ bioremediation system (Hinchee etc al. 1994).

Microbial processes also take place in the cycling of metals. Metals and their salts possess the capacity to inhibit biological processes. Some microorganisms develop mechanisms to protect themselves from the effects of toxic metals. The treatment methods applied to the metals are using this mechanism in their processes. Biological processes can be used effectively to change form, chemical state and distribution of metals. Technologies that are used include the mechanisms of bioleaching, bioextraction, biosorption, biological oxidation etc. These technologies have the potential for use in the remediation processes, although they are not well developed yet. (Means and Hinchee 1994).

2.5.3 Constructed Wetlands

The wetlands can also be considered as a method of the wastewater treatment. The mechanism is quite easy. The constructed wetlands are usually shallow about 0.6 m deep bodies of slow-moving water in which water-tolerant plants such as cattails, reeds, bulrushes are growing. Typically, constructed wetland can perform treatment better that natural, since their bottom is usually graded and hydraulic regime is controlled. It is possible to achieve the property of water of a secondary/tertiary treatment if the system design and treatment methods are properly developed. Typically, constructed wetlands can be classified into 2 types: **free water surface** (FWS) with shallow water depth and **subsurface flow** (SF) or vegetated submerged bed (VSB), with water flowing laterally through the sand and gravel (Copper and Findlater 1990).

Wetland systems can significantly reduce biochemical oxygen demand (BOD_5), suspended solids and nitrogen, as well as metals, trace organics and pathogens. The basic treatment mechanisms include sedimentation, chemical precipitation and adsorption. Bacteria near the plant roots biodegrade the contaminants in the water. Chemicals and metals are adsorbed by the soil.

The system of metals bioremediation includes natural biochemical and biological processes for removal of metals. Usually the wetlands represent an aerobic zone on the surface and the anaerobic zone below the surface. Aerobic reactions provide the opportunity for the removal of insoluble oxides. While anaerobic reactions are responsible for sulfate reduction. (Means and Hinchee 1994).

Wetlands system can also be suitable for the treatment of produced water and contaminated run-off. This technology is based on the bioremediation process for degradation of hydrocarbons in the microbial processes and adsorption of heavy metals. If the quality of the water after the treatment process is in the compliance with all the standards, there is an option to use it for irrigation purposes.

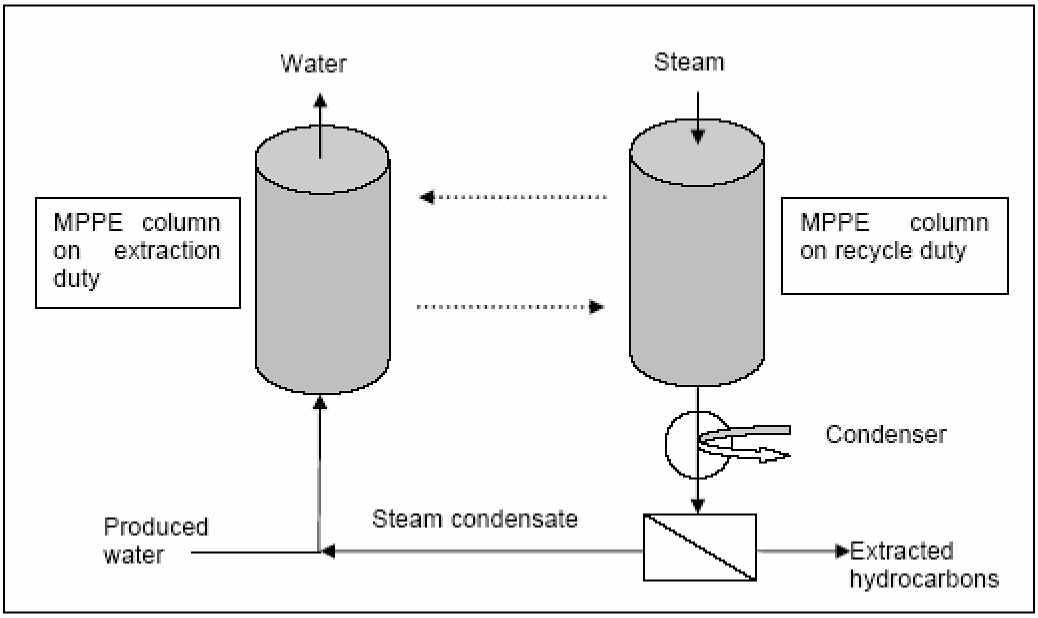
The experiments for the treatment of oil produced water was conducted by Ji *et al* (2006) in Liaohe Oilfield in China. As a result the conclusion was made that this treatment method can remove large amounts of COD and mineral oil from the oil-produced water while pH levels remain unaffected by the wetlands treatment method. The results proved that the wetlands can be used as an effective method for the treatment of heavy oil-produced water (Ji *et al* 2006).

Notwithstanding all the benefits of the constructed wetland treatment technology, its usage can generate some concerns. First of all, the produced water usually contains high level of salinity and special investigations have to be conducted on the effectiveness of treatment in these circumstances. Second potential problem is the blockage of filtering channels that will require continuous monitoring. Third, is the area requirement, as this method will occupy a lot of land (BP 2006).

2.5.4 Macro-Porous Polymer Extraction (MPPE)

The MPPE technology was introduced in 1990. MPPE removes dissolved and dispersed hydrocarbons. This technology is based on the liquid-liquid extraction process. It utilizes porous polymer beads containing extraction liquid. This liquid is responsible for the removal of hydrocarbon from water. The extraction water is intercepted by micro-porous polymer particle. The technology is used for process water, produced water, and groundwater treatment. For the MPPE process to function properly the wastewater should be pre-treated to remove the heavy metals. In the process the hydrocarbons are condensed and then separated from water under the process of gravity. As a result hydrocarbon for 100% are removed from process, and separated water can be re-used in the process. The following components can be removed in the process of MPP extraction: BTEXs, PAHs, aliphatic etc. As it was discussed above the produced water usually contains corrosion inhibitors. The MPPE techniques also can remove some part of these chemicals. The running of this technology does not require a lot of labor force as the processes are fully automated and it can be controlled remotely. The system is suitable for outdoor installation. The consumption of energy and generation of noise are minimal. (Azko Nobel MPP Systems 2004).

Produced water can have different composition. MPPE technology removes specific hydrocarbons, and some of them, which can be characteristics of some produced waters, may remain in the treated water. From that point of view MPPE should be carefully considered for the specific cases. Another point, which should be considered, is the hazardous sludge, which will be generated in the process of MPPE. (AGC Produced Water ESIA 2006). Diagram 1:



Source: Akzo Nobel MPP Systems 2004: http://www.touchbriefings.com/pdf/951/Akzo_tech.pdf

In addition to MPPE there are other membranes technologies available on the World Market. For example, porous ceramic membranes. The research conducted by the Norwegian University of Science and Technology (2000) demonstrated that ceramic membranes are capable of removing the oil from produced water to 3 mg/l. They are easy to clean and resistant to high temperatures and different chemical substances. The membranes consist of porous tube with a layer of small pores. This layer is captures oil and particles under the water pressure. (Sterlitech Corporation 2002).

Nanofiltration is a process of separation driven by pressure and based on the layer formed by organic semipermeable membrane. These membranes have smallest spectrum of pores. It has unique separation characteristics and can fractionate sulphate from chlorides.

2.5.5 Multi-Stage Flash (MSF)

This technology was developed in 1950. It is typically used for desalination of seawater. The seawater entering the MSF system's brine heater undergoes the heating by the condensed water. After the brine heater the water passed to the next chamber. In this chamber the pressure is considerably lower than in the brine heater and under this conditions water start boiling rapidly. The water passes through different stages and each time the atmospheric pressure reduces. As a result the water is continuously boiled without adding more heat. Each stage is equipped with the tubes of heat exchangers, where the fresh water is condensed. The system operated under 90-120 °C. Usually the MSF is considered costly technology. Generation of salt as by-product is another problem with the MSF. In addition, due to the high temperatures used in the system, corrosion of the equipment is considered as a problem. (National Science Foundation 1993). Diagram 2: MSF process

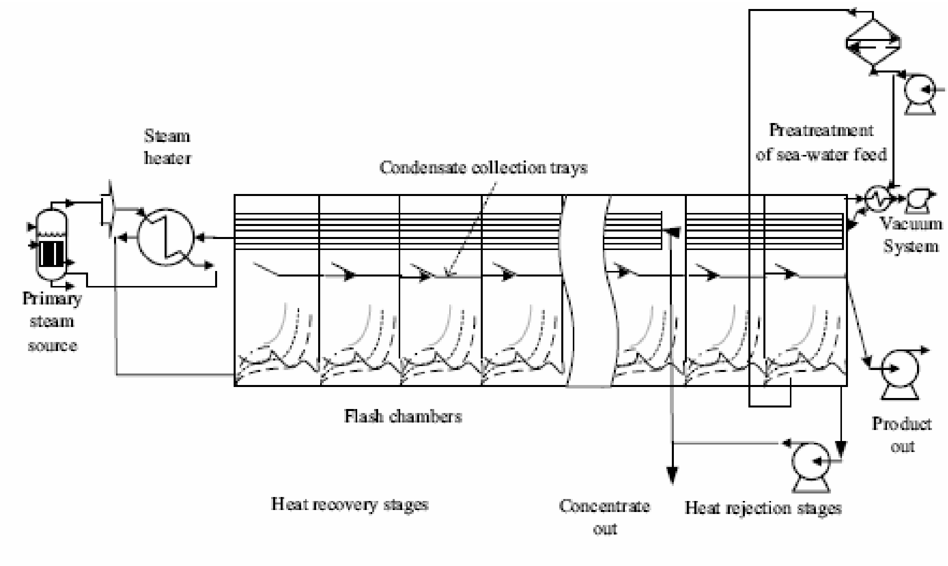
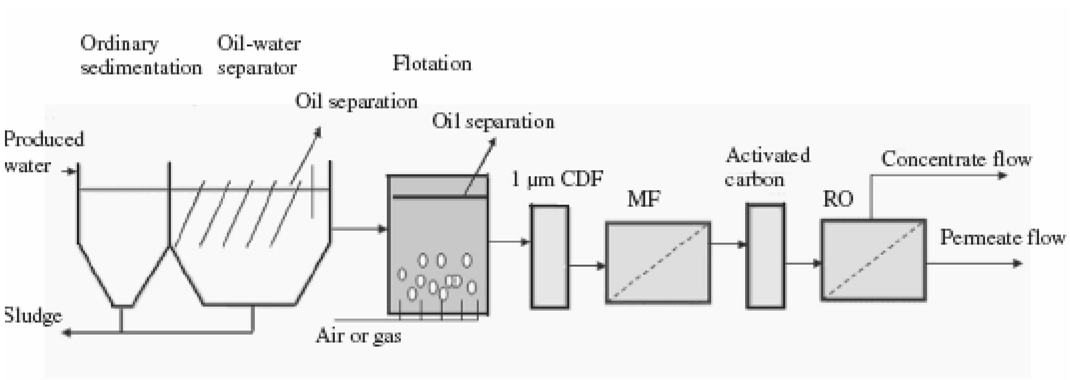


Figure 2. Schematic presentation of a Multi-Stage Flash desalination plant.
Source: National Science Foundation 1993: http://www.iwra.siu.edu/win/win2000/win03-00/semiat.pdf

2.5.6 Reverse Osmosis (RO)

RO technology is very effective in removing of dissolved solids, bacteria, and organic contaminants. RO can treat the brine water with the salinity level of 45,000 ppm. In RO the mechanism of thin synthetic semi-permeable membrane is used. Its pores are large enough to pass water molecules but too small for larger molecules. Water pressure forces water molecules through the membrane while leaving the larger molecules behind. Reverse Osmosis process is based on the reversal of water flow from high salinity to the permeate stream on the opposite side of the membrane. The separation process is performed under the pressure. The pressure used is higher than the osmosis pressure of the contaminated substances that allows the flow process along the membrane. (GE Waters and Process Technologies 2008).

The using of RO technology as the final treatment stage of the produced water to remove salt was investigated by Cakmakci *et al* (2007). The experiments were conducted with the Trakya oil production field produced water to define the treatment combinations to achieve the water quality level permissible for discharge into the environment. Initially the produced water was passed through the screening stage, when larger particles were removed, for that 5 and 1 μ filters were used. During the next stage the Micro Filtration and Ultra Filtration were used as a pre-treatment. The processes of coagulation, floatation and organic materials cracking also were performed at the pre-treatment stage. The final stage was the salinity removal for which RO and NanoFiltration technologies were used. After the experiments the authors came to the conclusion that RO membranes can be used effectively for the treatment of the produced water after the pre-treatment processes. Different combinations were tried to reach pre-treatment quality suitable for RO use. The conclusion was made that primary sedimentation, followed by separation of oil from water, then Dissolved Air Flotation technique followed by cartridge filter and microfiltration give the best composition after the pre-treatment that is successfully treated by RO (the process is shown in the diagram 3 below).



Source of data: Cakmakci *et al*. 2007

2.5.7 Ion Exchange

This technology can be used for the removal of heavy metals and hardness from the produced water. It is based on the chemical reaction in which ion from solution is exchanged for another ion, with the similar charge attached to the solid particle. The solid ion exchange particles can occur naturally or be synthetically produced (Remco Emgineering 2007).

Hydrometrics Inc (USA) – engineering company – developed a system in which cation exchange is used to treat produced water. Weak Acid Cation exchange process removes sodium and releases acidity. Total Dissolved Solids are removed from the produced water as well. (URS 2002).

It is impossible to decide on the effective method to be used for the produced water treatment merely by using the literature available due to the fact that the produced water characteristics are different. In this part the description of the worldwide available technologies is only given, the experimental investigation should be conducted on site to decide what method is the most appropriate in the particular cases.

2.6 Integrated Approach to Wastewater Management

Water is a precious finite resource, needed for humans and ecosystems. Nowadays the availability of this resource is declining. In most cases water resources are used in non-sustainable way (Meire and Coenen 2007). In response to that the integrated water management concept has been recently developed. This concept has been initially mentioned at UN Stockholm Conference in 1972 and found its development at Rio Conference, when this concept was mentioned in Agenda 21 (Meire and Coenen 2007). The holistic approach to water management is the main idea behind this concept. To manage the water in a sustainable way such aspects as environmental, social, legislative and economic have to be integrated.

Wastewater re-use is one of the components of integrated water management tool. The inclusion of this water re-use concepts into the water resources management can have a lot of benefits contributing to the sustainability of water resources supply (Miller 2005). The wastewater re-use concepts, nevertheless, face different barriers in the phase of their development. Although, the available technologies can provide the opportunity for the water purification to the levels acceptable for the re-use purposes, the legislative and social issues are still to be overcome for the successful implementation of this concept. (Hochstrat et al. 2006).

Water re-use concept is now becoming popular in many countries of the world, especially in the countries, which experience problems with water scarcity. Water re-use strategies are mostly developed in such countries as US, Australia, Israel (Miller 2005). Usually the re-use practices are applied in the following three area (Hochstrat et al. 2006):

- re-use for the irrigation purposes and other industrial needs, thus covering the exiting water demand;
- re-use for environmental enhancement
- re-use for the purposes to support natural resources (for example, for ground water support oil reservoir enhancement).

The research conducted in this area (Miller 2005) indicate that there are the main issues, which determine the success of integrated wastewater management implementation, such as:

- project design, which should be developed with clear objectives, proper consolation and with environmental and economic considerations
- Regulations in this fields, which do not exist in many countries. Even across the Europe these regulation vary considerably
- Technological aspects, which should correspond to the intended use quality requirements
- Safety of the water re-use from its chemical and microbial composition point of view
- Public awareness and acceptance of the re-use practices. In this respect negative reaction of population to the re-use of wastewater has to be overcome.

The definition of water re-use boundaries is an important element of the overall wastewater strategy, where the main goals of the re-use should be taken into account. The development of the guidelines for the wastewater re-use is another challenge, which is intended to be overcome in near future with all the efforts of scientists and water professionals. (Miller 2005).

2.7 Summary of the Literature Review

The current literature review has been generally focussed on the produced water and open drain water specific characteristics review and the technologies available worldwide and in Azerbaijan particularly, which can provide opportunity for the environmentally sustainable re-use and harmless discharges of wastewater into the environment. The BAT and concepts of integrated wastewater management have also been covered in this section of the thesis. Produced water, which is the one of the main wastewater streams associated with the oil and gas extraction processes, has found a lot of consideration among the researches and water professionals, which yielded in numerous researches, books and other materials on produced water around the world. There are theories existing about the BAT and the re-use concepts of the produced water. In Azerbaijan there are not any considerable studies developed in this field, especially the integrated wastewater concepts and the possibilities of the water reuse did not find any special consideration. Locally, there are some technologies available but most of them exist potentially, that means in the theory and have never been tested or implemented. In Azerbaijan, which has long history of the oil and gas extraction, wastewater management is very crucial issue, due to the fact that most extraction facilities are located offshore and the Caspian Sea is a sensitive closed aquatic system. This thesis is intended to contribute to the development of studies related to the treatment and management of produced water and open drain water. It will fill the gap existing currently in the available literature on the technological and management aspect of the wastewater from Oil and Gas Industry, specifically applicable to Azerbaijan.

Chapter 3. Methodology

This Section describes the methods used for data collection and analysis. The present thesis represents the combination of qualitative and quantitative study on the wastewater generated by oil industry in Azerbaijan, its volumes, treatment, disposal methods, environmental impacts related to it and possibilities to mitigate them by using new technologies. The information was gathered by means of interviews with Oil & Gas Industry and Environmental experts and desktop studies.

3.1 Research Design

Complex of different scientific and research methods was applied to ensure that this study meets its objectives. A combination of purposeful sampling strategies was used during the research. Analytical methods were used to review and analyze data on volumes of wastewater generated, volumes of water disposed and reused. Comparative method was used for studying the cases and comparing them between each other and industry's best practice in dealing with wastewater issues. The whole process of comparative analysis consisted of case selection process, case study and case comparison. Gap analysis was conducted between existing methodology of wastewater treatment of BP and SOCAR and for the assessment of the areas of improvement. Finally, for the purposes of the Recommendation Section the assessment criteria was used, which is based on the calculating the advantages and disadvantages of the existing technologies, used by the different parties being at discussion in this work, and providing comprehensive comparison between them.

To find the answer for the research question, which is built on the theory of possible synergy between oil industries and sustainable development, the case study has been conducted. The purpose of the case study was to develop an understanding on the technologies available for oil industries and how they can mitigate the environmental impacts of wastewater and ultimately contribute to the sustainability of oil industries. The case study conducted falls better under the category of "collective study" suggested by K. Punch (1998). In this category of study the several cases are covered to provide better understanding on the phenomena. This "collective case study" provides opportunity to analyze the situation with wastewater management and treatment from the perspective of detailed study and comparison. The holistic approach was used for the analysis of case studies, based on the understanding the uniqueness of the specific case being on consideration and from that perspective framing it to the wholeness of the system. Some authors mention the "boundaries" of the case studies

(Stake 1999; Punch 1998). For the purposes of this work the case study boundaries will be defined first, geographically, as the wastewater treatment technologies applied by the companies involved in the activities on the Caspian Sea will be considered. This boundary is set due to the specific regulations on the wastewater discharges applied to extraction industry operation on the Caspian Sea. The second boundary, is the technological, as only specific wastewater streams and technologies for their treatment will be considered, due to their nature. There are different methods and technologies exist worldwide for dealing with the produced water and open drain water, wastewater streams chosen for the research purposes. Not all of the technologies available worldwide are represented in Azerbaijan. That is related to the financial issues and lack of comprehensive studies on the produced water and open drain water treatment and management in the country.

The cases for studies have been selected due to the fact that they are the best examples for the subject study, taking into the consideration the "boundaries". Both cases are the most representative and their comparison provides opportunity to learn about the subject and the current state of the phenomena.

For this research purposes the information was gathered in the course of interviews with people responsible for management and treatment of wastewater as well as those responsible for environmental management in the companies. Another source of data collection is desktop research, which was conducted for the purpose of gaining understanding of the treatment technologies, practices used by the companies, environmental aspects of wastewater treatment and management in Oil Industries and related legislation.

Desktop studies, site visits and interviews were aimed at collection of the following data:

- what type of treatment is used for produced water and open drain run-off
- how the efficiency of water treatment is monitored and by whom
- which standards are used to monitor the water treatment and
- some other specific issues, which ultimately helped to assess the oil companies' practices of waste water treatment.

The research trip to study the cases was conducted in May 5th - 23rd 2008. During this time data related to waste water streams associated with the BP's Azerbaijan Strategic Performance

(AzSPU) and SOCAR was collected. This was done by conducting interviews with staff in the BP Baku offices and at Sangachal terminal in addition to reviewing available materials and documentation related to the subject.

3.2 Data Gathering

3.2.1 Site Visits

During the research for the purpose of data gathering the visits to Azerbaijan BP AzSPU sites were performed. Sangachal Terminal was chosen for the conduction of field trip due to the fact that this facility receives the crude oil from all the offshore platforms, which is subsequently undergoes the process of gas, oil and water separation. The produced water, generated as a result of these preliminary treatment, is then treated at the special treatment facilities and if required stored at the specially designed Storage Tanks or Evaporation Ponds. In other words, Sangachal Terminal represent the main area of interest for the current study as it is the place where the produced water is generated and is further handled.

Overall, site visits were performed to collect the data, to see the wastewater-related processes going on at sites and to understand the nature of these processes. Also it was useful to interview site operators and workers and ask them to explain the part of work they are responsible for. That usually is helpful as people can explain in their own words the difficult technological aspects that are described in the Manuals or other Technical documents with a lot of technical terminology.

3.2.2 Interviews

"Interviewing provides the access to the context of people's behavior and thereby provides a way for researches to understand the meaning of that behavior" (Seidman 1998).

Seeking the way to "understand this behavior" a series of interview with people responsible for wastewater treatment in Oil Industry of Azerbaijan was undertaken. The interviews with representatives of BP AzSPU Environmental and Engineering Teams – Onshore Performance Unit (PU) Health, Safety and Environmental (HSE) Manager, Onshore PU Deputy Environmental Manager and Sangachal Terminal Environmental Advisors, personnel involved in produced water controlling activities and other experts in Central HSE Team of BP Azerbaijan Performance Unit were conducted. Overall, four interviews were conducted with BP representatives during the site visit. These people were chosen based on the positions they take in BP AzSPU and their responsibilities related to wastewater treatment.

Initially it was planned to interview people from SOCAR, responsible for produced water and open drain water treatment and management and those involved in the environmental issues in day-to-day oil and gas operations. Unfortunately, only one person from SOCAR Environmental Department participated in the interview. This interview with SOCAR though is considered unofficial. It means that the person agreed for an interview with the condition than his name would not be revealed in this work. From the Ethics standpoint the data collected during this interview is referenced as “unofficial personal communication”.

All the interviews were conducted based on the prepared Interview Matrix. For the purposes of the qualitative analysis the interviews conducted with the selected people were aimed at finding out the opinion of experts on the problems of wastewater treatment, efficiency of the existing technologies and their vision for future technological development.

Semi-structured interview technique was used. The questions asked are mostly open-ended and descriptive, some of them are “grand tour” questions, asking the interviewee to describe the processes of wastewater treatment for example (Spradley 1979).

3.2.3 Document Review – Desktop Studies

The desktop studies approach was used to review the existing documentation in the Companies in order to understand the context within which the wastewater management is being performed. In addition, desktop research was conducted to review the wastewater treatment projects existing in oil industry worldwide to study the best practices and available technologies. The main goal of the documents review was to identify the Companies' approaches to the wastewater treatment, to define the main risks assessment conducted by companies and find out about the practices and technologies used.

Overall, desktop study had the following objectives:

- development of understanding of the Companies' approaches to wastewater management and treatment
- reviewing the available technologies used by the Companies
- reviewing the environmental issues related to the wastewater treatment and the way the companies are dealing with them
- gaining the information about the companies short-term, interim-term and long-term approached to the problem of increasing volumes of wastewater streams

- reviewing the worldwide practices in oil industry related wastewater management and treatment and the successful projects implemented

The following BP AzSPU Documents have been reviewed in the process of the desktop studies:

1. EIA for discharge of treated produced water via long sea outfall from Sangachal Terminal
2. Environmental Strategy for produced water disposal
3. Water treatment installation description
4. Study for the Reuse of Produced Water as Irrigation Water
5. Monitoring Program for sewage treatment
6. Effluent inventory for Sangachal terminal
7. Status of Sangachal Terminal Produced Water Management
8. Info on applicable EU and International Legislation
9. And a lot of other kind of information like the correspondence with the Ministry of Ecology and Natural Resources of Azerbaijan Republic, power-point presentations, some research and monitoring data.

3.2.4 Produced Water Odor Tests

At the time of site visit to BP Sangachal Terminal the produced water odor study was conducted by Environmental Department of the terminal. The participation in the odor testing directed to identify the different nuisance levels of treated and untreated produced waters and their comparison, gave the opportunity to gain the better insight on the issue. It helped to develop an understanding on the specific issues related to the odor nuisance, being one of the impacts of this wastewater stream. The analyses of these test results constitute the part of the case study.

3.3 Data Analysis

All the data, which was gathered during the different stages of the research work, afterwards had undergone the process of examination and analysis. Analyzing the data was performed by different methods the aim of which is to break down the data into smaller units, examine these units and then compare them for similarities and differences (Stauss, and Corbin 1998). Comparative Analysis and Gap Analysis methods were used for that comparison and identification of the gaps between the data. Furthermore, the data collected during the research was analyzed using the three-stage approach suggested by K. Punch (1998). It was reduced through the process of analysis, then displayed and finally based on the reduction and the display the conclusions were drawn. After the finalizing the analysis the conclusions have been verified.

The data derived from interviews has been compared with the existing companies' documentation, describing technologies, treatment methodologies and management issues. The available documentation in its turn has been compared with the existing worldwide practices in this field. Furthermore, the documentation reviewed has been compared with the existing national and international legislation to verify the compliance with the main wastewater treatment and management laws and standards' requirements.

3.4 Limitations

During the research process a number of limitations were encountered.

Produced water represents a sensitive topic to BP AzSPU as the company has just prepared the new Environmental Impact Assessment for the newly implemented methods of produced water treatment at Sangachal Terminal and is now involved in EIA discussion with the MENR. The latter fact can also be defined as a limitation as the system implemented is new and its long-term performance cannot be analyzed. Newly implemented technologies do not allow seeing work from a time perspective.

No formal interviews were conducted with the representatives of SOCAR. There was difficulty encountered in obtaining data from SOCAR. The data, which was collected on produced water related to SOCAR operations, is scarce and scattered and due to that the comparative analysis process was complicated. The data on open drain water is not available for SOCAR at all. In this regard, the initially planned comparison analysis on the treatment and management of SOCAR and BP open drain wastewater has not been conducted. As a result the comparison analysis was concentrated on the produced water instead of both streams.

Due to time limitations the travel to all offshore platforms was not performed. It would not have great impact on the whole work as desktop studies and review of available drawings and technical notes can compensate this limitation.

As results of these limitations the current work was based on the following resources:

- BP AzSPU Documentation
- Worldwide existing technologies
- Formal Interviews with BP AzSPU Representatives
- SOCAR articles on produced water
- Unofficial Interviews with SOCAR representatives (the data collected from this interviewed is referenced as unofficial, without indication of the name of person who was interviewed)
- SOCAR documents describing technical aspects of wastewater treatment
- GOST standards in accordance with which the produced water management and treatment is performed by SOCAR

3.4.1 Confidentiality

The part of this work related to the technological aspects of wastewater treatment represents confidential material of BP AzSPU and by the request of the company should be treated accordingly.

Also, some o the interviews with the representatives of SOCAR cannot be named by the request of the interviewees.

3.5 Ethics

During the research the ethics issues have been considered, especially where research was based on the interaction with people. In this regard, all the interviewees initially were informed about the purpose of the research and their consent for the participation in the research was obtained. In case when the interviewees expressed the wish not to identify them in the research, the respect for the confidentially was provided and their names are not mentioned here. Finally, all the participants received information about the research results.

Chapter 4: Overview of Existing Legislation Related to Oil Industry Wastewater

4.1 International Legislation

Since 1991 Azerbaijan has signed a number of International Conventions. By the Law of the Azerbaijan Republic, the International Conventions after their Ratification by the Parliament of the Republic automatically become the Laws of the Republic and incorporated into Azerbaijan State legislation.

The following International Conventions will be overviewed as they can refer to the wastewater and activities of companies involves in Oil & Gas industry:

- MARPOL 73/78 – Prevention of Pollution from Ships
- Convention on the Protection and Use of Transboundary Watercourses and International Lakes, Helsinki, 1992
- Convention on Environmental Impact Assessment in Transboundary Context, Espoo, 1991
- Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, Basel, 1992
- Convention on the Conservation of European Wildlife and Natural Habitat, Bern, 1979
- Convention on Access to Information, Public Participation in Decision Making and Access to Justice in Environmental Matters, Aarhus, 1998

The table below (Table 8) summarizes the main requirement of these international conventions and treaties.

Table 8: Brief Summary of International Conventions Requirements

Name of the Convention	*Ratification by Azerbaijan*	*Brief Summary*
MARPOL 73/78 – Prevention of Pollution from Ships	Baku, 1997	MARPOL Convention regulates the pollution, caused by shipping by results of their routine operations or accidents on the watercourses. The Convention consists of six Chapters. In the Convention there is a concept of “special areas” introduced, where the discharged to seas are prohibited due to sensitivity of this aquatic ecosystems. Although, the list of Sea as Special areas does not include the Caspian Sea, some provisions of the Convention can be relevant to the produced water related issues being in consideration in this work. Some of the issues mentioned in the Convention are related to the Oil in Water concentrations of the produced waters and water effluents. In accordance with the Convention (MARPOL 73/78):
Convention on the Protection and Use of Transboundary Watercourses and International Lakes	Baku, 2000	The transboundary impacts of water pollution are the subjects of this Convention. The main idea of the Convention is to control, prevent and mitigate any impacts on the water caused by transboundary pollution. The term “transboundary waters” is defined for the purposes of the Convention as ground or surface

		waters, located on the boundaries or passing through the boundaries of another state being the signer of the Convention. The Protocol on Water and Health being the part of the Convention (ratified by Azerbaijan in 2005) was developed to protect aquatic ecosystem in order to protect human health From the other countries located on the Caspian Sea, Kazakhstan and Russian Federation have signed this Convention.
Convention on Environmental Impact Assessment in Transboundary Context	Baku, 2000	This Convention is specifically requires the development of ESIA processes as a significant tool for the sustainable development in the transboundary context and for the protection the environment, including watercourses, from environmental degradation related to different activities. Azerbaijan, ratified this Convention in 2000 and now under the conditions of this agreement, there is a requirement to properly inform the other signatories of the Convention about any potential impacts of the activities on the territory of Azerbaijan that can ultimately impact these countries. The activities covered by the agreement include the water-related developments.
Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal	Baku, 2001	Although, the Convention is primarily deals with the hazardous wastes transboundary movement, but there are some provisions requiring the parties to implement the following measures for the control over the generation, treatment and management of the hazardous wastes on their territories. This agreement is specifically requires the countries, being the signatory to the Convention: ▪ To make the steps to the reduction of hazardous wastes generation. ▪ To implement existing technological, economic and other measures to ensure the minimization of hazardous wastes ▪ To manage the hazardous wastes and provide the opportunities for proper disposal and treatment facilities ▪ To prevent the pollution from the hazardous wastes by all the available means ▪ Provide information on the amount of hazardous wastes generated, their types and their imports/exports.
Convention on the Conservation of European Wildlife and Natural Habitat	Baku, 1999	The provisions of this Convention cover the coast and coastal zones, and wildlife. The wastes and wastewater can have potential impacts on this habitat and the biodiversity. Azerbaijan signing this Convention had taken the commitments on the assessment of potential impacts related flora and fauna, and manage the conservation activities directed at protection of these species and their habitats.
Convention on Access to Information, Public Participation in Decision Making and Access to Justice in Environmental Matters	Baku, 1999	Under this Convention the public of the countries signed it possess the rights to access the information, participate in decision making on the issues that are related to their health and environment. The main provisions of the Convention guarantees that: ▪ The local authorities should provide the environmental related information to the public by their request. ▪ The local authorities periodically distribute this information among people through the publicly available resources ▪ The public participation in the decision-making is encouraged by the authorities ▪ Environmental plans and programs are properly prepared and made available to people, seeking for their participation in projects planning activities.

Source: MARPOL 73/78; Convention on the Protection and Use of Transboundary Watercourses and International Lakes (1992); Convention on Environmental Impact Assessment in Transboundary Context (1991);

Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (1992); Convention on the Conservation of European Wildlife and Natural Habitat (1979); Convention on Access to Information, Public Participation in Decision Making and Access to Justice in Environmental Matters (1998)

There is another convention, which should be mentioned in this chapter as it is related to the protection of the Caspian Sea environment, the **Framework Convention for the Protection of the Marine Environment of the Caspian Sea** (Tehran, 2003). It has not been ratified by Azerbaijan yet and is not the Law of the country but it worth mentioning the main provisions of this convention in the context of wastewater and the Caspian Sea environment. The main provisions of the Convention are related to the pollution prevention and control measures for the protection of the Caspian Sea environment. Article 2, defining the objectives of the Convention, states that biological resources of the Caspian Sea should be protected, preserved and used in a sustainable manner. The scope of the convention, under the Article 3, is the Marine Environment of the Caspian Sea. Article 9 defines the obligations of the parties to reduce and prevent pollution and develops measures for pollution control. The cooperation between the countries, are provided in the Article 16, which includes scientific research and programs for the investigation of the Caspian Sea fluctuations. The Convention will become the Law of the Republic in case if Azerbaijan ratifies it.

4.2 National Legislation

In the post-Soviet period the main changes in the development of environmental related legislation were predetermined by the adopted the Constitution of the Azerbaijan republic. The Constitution states that the environment and the natural resources belong to the people of the Azerbaijan Republic, and that the Government, will take the necessary measures to protect the environment and rationally use the natural resources (Azerbaijan Law 1995) The basic environmental document, the Law on the Protection of the Environment, was adopted in 1995 and amended in 1999. The other basic environmental related laws were adopted later, such as Water Code of the Azerbaijan Republic, Water Supply and Wastewater Law, Forestry protection law and others. At the same time, there are other environmental Laws and Regulations, which were adopted during Soviet times and still remain in power.

In Azerbaijan for the development of main private and public projects the Environment and Social Impact Assessment process is a requirement (Handbook for EIA Process 1996). The ESIA requirement was implemented by the Ministry of Environment and Natural Resources (MENR) by the Law of the Azerbaijan Republic on the Protection of the Environment Law

(Environmental Law 1999). After the submission of the project the period of ESIA review is three months (Handbook for ESIA process 1996).

4.2.1 Regulatory Agencies in the Azerbaijan Republic

The Ministry of Environment and Natural Resources is the main environmental regulatory body in the Azerbaijan Republic. The MENR was established in 2001 by merging the different State Committees, such as State Forestry Committee, State Committee for the Environment, State Committee for the Hydrometereology, Committee of Geology. This Governmental body has the following responsibilities:

- ✓ Implementation of the National Environmental policy
- ✓ Development of environmental related policy for submission to the Parliament
- ✓ Enforcement of environmental standards and regulations
- ✓ Review and approval of ESIAs
- ✓ Provide advises on environmental related issues
- ✓ Ensure the implementation of the provisions of the International Conventions.

For the purposes of this work the following National Laws and Regulations related to the wastewater and oil & gas industry activities will be overviewed:

- Law of the Azerbaijan Republic on Water Supply and Wastewater, Presidential Law 1999
- Decree on Types of Productions and Enterprises Where Disposal (Release) of Industrial Wastes is Prohibited, Cabinet of Ministers, 2000
- Environmental Protection of Hydrosphere, Rules for Quality Control of Sea-water, USSR, State Standard, Moscow, 1982
- Environmental Protection: Hydrosphere: Purification of Waste Water in Offshore Oil Production, Basic Requirements Towards Purification Quality, USSR, Branch Standard, 1984
- Protection of Nature, the hydrosphere, rules for protection of sea from pollution in oil production and the repair of wells of the marine fields, Committee of Oil & Gas Production, 1992
- Provisional Instructions on the Manner for Undertaking Evaluations of the Effects on the Environment During the Development Works on Offshore Hydrocarbon Fields, Ministry of Oil & Gas, 1990

Table below (Table 9) provides summary of the main requirements of the National Laws and Regulations related to the wastewater treatment.

Table 9: Brief Summary of International Conventions Requirements

Name of the Law	*Brief Summary*
Law of the Azerbaijan Republic On Water Supply and Wastewater	The main objectives of this law, described in Article 2 are related to the provision of required volumes of water for the population and industrial needs. In accordance with this Law (Article 39) the following industrial wastewater streams should not be discharged into the sewage system: ▪ Rain Water ▪ Oil Products ▪ Calcium Carbide ▪ Prohibited wastewater streams The same provision identifies exceptional cases, when the industrial waste generator signs the agreements with treatment enterprises for the disposal of the wastewater. In this cases when the agreement is reached the conditions of wastewater treatment and responsible party are described there.
Decree On Types of Productions and Enterprises Where Disposal (Release) of Industrial Wastes is Prohibited	In accordance with this Law the wastewater produced by the following production activities are fall under the category of industries for which the disposal of industrial waters into the communal sewer is prohibited: ▪ Productions and enterprises from oil production and oil processing sector; ▪ Productions and enterprises from area of chemical industry; ▪ Productions from oil-chemistry industry.
Environmental Protection of Hydrosphere, Rules for Quality Control of Sea-water	These rules are describing the objects, where the control of water quality should be implemented. The following places are determined by the rules as those requiring water quality control: ▪ sewage discharges places ▪ places of exploration, exploitation and transpiration of mineral resources ▪ population use waters ▪ discharges from industrial and agricultural complexes In the regulation, the rules and frequency of the programs for the monitoring of water quality are described and stipulated. The cooperation with other organization on the exchange of monitoring information is set as a requirement.
Environmental Protection: Hydrosphere: Purification of Waste Water in Offshore Oil Production, Basic Requirements Towards Purification Quality	This standard was adopted for the establishment of basic requirements for the quality of purification of wastewater produced in the process of oil and gas fields development. Paragraph 3 of the current requirement specifies the level of different components of the process and process-rain wastewater after the treatment process, (the water to be recycled in the supply systems for cooling compressors): The standard further described the requirements for the re-injection processes, composition of injection water, requirement of well selection of re-injection, the content of suspended particles and etc. The provisions of the standard recommend, where practical, to use the produced water for reservoir injection.
Protection of Nature, the hydrosphere, rules for protection of sea from pollution in oil production and the repair of wells of the marine fields	This Standard was adopted to set the rules for the protection of seawaters from the activities related to the offshore oil & gas production. The main provision of the Standard states that the discharges of oil and gas production waters, as well as contaminated run-off into the Caspian Sea are forbidden. The same provision sets the rule for the produced wastewater re-injection into the well, or if this option is not available, the collection the water into special containers and its transportation to the onshore installations for treatment. The system of

	equipment used on the offshore vessels and platforms and methods of wells operations are described in the standard. The decommissioning and abandonment of the wells after their depletion is described in Articlev4. The Elimination of Emergency situations and the availability of the Emergency Response measures are set by this standard (Article 5).
Provisional Instructions on the Manner for Undertaking Evaluations of the Effects on the Environment During the Development Works on Offshore Hydrocarbon Fields	This Instruction is a set of rules on the evaluation of effects on the environment, which described the process for the determining the nature and the extent of hazards, which can potentially influence the environment in the course of industrial activities. The mechanism for the calculating of ecological factors during the design activities of the industrial projects is described in this instruction. The main concept introduced by this regulation is that environmental impact evaluation must contain elements of research directed at more complete understanding of the processes influencing the environment in the process of hydrocarbon related activities.

Source: Law of the Azerbaijan Republic on Water Supply and Wastewater, Presidential Law 1999; Decree on Types of Productions and Enterprises Where Disposal (Release) of Industrial Wastes is Prohibited, Cabinet of Ministers, 2000; Environmental Protection of Hydrosphere, Rules for Quality Control of Sea-water, USSR, State Standard, Moscow, 1982; Environmental Protection: Hydrosphere: Purification of Waste Water in Offshore Oil Production, Basic Requirements Towards Purification Quality, USSR, Branch Standard, 1984; Protection of Nature, the hydrosphere, rules for protection of sea from pollution in oil production and the repair of wells of the marine fields, Committee of Oil & Gas Production, 1992; Provisional Instructions on the Manner for Undertaking Evaluations of the Effects on the Environment During the Development Works on Offshore Hydrocarbon Fields, Ministry of Oil & Gas, 1990

Chapter 5: Produced and Open Drain Water: BP Case Study

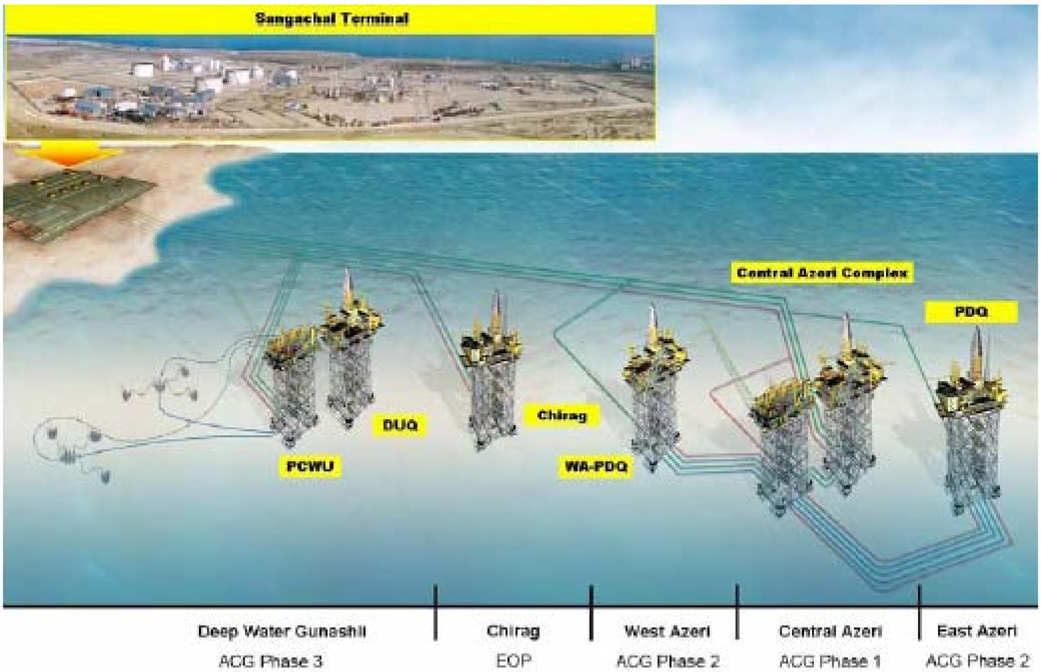
5.1 BP AzSPU Facilities

On site data collection at the AzSPU facilities gave a good overall picture on company range, i.e. different offshore and onshore activities and potential sources for wastewater generation. The following brief information about the company's facilities and their locations are given based on the material provided by the company.

5.1.1 Offshore Facilities

About 80% of Azerbaijan oil development projects are located offshore. From onshore facilities BP operates pipelines and pumping and pigging stations. Azeri-Chirag and deep water Guneshli (ACG) is the largest oil field on the South Caspian located 100km east of Baku. BP AzSPU is the operator of the Azerbaijan International Operating Company (AIOC) (BP 2005). The estimated oil reserves in the ACG field are about 5.4 billion barrels of oil. The development of ACG fields has been performed in 3 phases. The production of ACG started in 1997 with Chirag platform and is known as Early Oil Production (EOP), followed by ACG Phase 1 i.e. Central Azeri, then by ACG Phase 2 i.e. East and West Azeri and then ACG Phase 3 i.e. Deep water Guneshli which is two platforms: Drilling, Utility and Quarters and Production, Compression Water Injection (BP 2006a). Figure 1 illustrates the positioning of these platforms in the Caspian Sea.

Figure 1: EOP and ACG Platforms



Source: BP ACG Produced Water ESIA, 2006

BP also operates the Shah Deniz (SD) gas field which is located 70km offshore Azerbaijan in a very complex geologically structured area. SD is one of the largest natural gas fields discovered in 1999. The area covered by the SD field is 250 km^2 and it is expected that by 2010 the annual rate of natural gas supply from SD field will be 8.7 billion m^3. (BP 2005)
All the platforms mentioned here are generating the wastewater streams such as produced water, sewage water, drilling fluids. Produced water generated on the platforms, will be separated from the oil there and be re-injected into the well when the water cut is 5% or more. The remaining water component in oil is being streamed to the Sangachal Terminal.

5.1.2 Onshore Facilities

The onshore oil and gas processing facility Sangachal Terminal receives oil and gas from the platforms and this location was the main focus for the case study. Sangachal Terminal is one of the largest oil terminals in the world. It is located 55km south from Baku and occupies 500 hectares of land. The facility was constructed in 1996. (Ahmad 2008). The territory of the site is divided into sectors corresponding to each production phase, such as Shah Deniz, ACG Phase 1 etc. The system of Sangachal Terminal operation is combined, where each element of the system is operated independently. Control Rooms are controlling the site operations.

The purpose of the Terminal is to receive oil and gas from the eight offshore platforms, to process them and distribute to the market through the existing pipelines originating from the Terminal. The Terminal is all around covered by complex piping equipment and installations. The system of the pipelines coming to the Terminal and back from it counts for fourteen different pipelines. The Terminal was further expanded in accordance with the Sangachal Terminal Expansion Program (STEP). Currently in construction is the ACG produced water project facilities which are due to begin commissioning in September 2008 and be fully operational by early 2009. These comprise onshore produced water treatment facilities and a 14” pipeline offshore to pump treated produced water to Central Azeri Compression and Water Injection Platform (CA/CWP) platform for down well reinjection.

Currently the daily amount of processed oil & gas at the facility is 1.2 million barrels and 900 million cubic feet respectively (Ahmad 2008). The storage capacity of the crude oil at the facility is three million barrels (405,000 tones). In addition to oil storage tanks, the Terminal also has produced water storage tanks, oil and gas processing tanks, generators, pumps and other equipment. The capacity of the existing ACG produced water tank is 130,000 bbls. The ACG produced water project will deliver another identical tank (BP 2006a).

Figure 2. View of Sangachal Terminal

Source: BP Official web-site – 1999-2008 p.l.c **www.bp.com/sectiongenericarticle.do?categoryI...**

5.2 Overview of BP AzSPU Wastewater Management System

Wastewater treatment is critical to oil industry due to the specific nature and the impacts on the environment that it may cause. BP generates different types of liquid wastes, which should be managed and treated to the extent compliant with the international and local requirements. The company is using integrated approach to wastewater management where most attention is given to minimizing pollution at source. Management of produced water waste is one of the most important waste streams for BP AzSPU currently. A long term project is under construction as detailed in section 6.1.1 until this time interim options for produced water management are being operated. The disposal of produced water can have negative impacts on the environment due to its specific composition and volume. In addition worldwide, the regulations on the produced water discharge become more stringent (Dell *et al* 2007). Globally BP produces more water than oil. In Azerbaijan the volumes of generated produced water are predicted to increase as it is usually happens with the aging of wells. The technical capacities at the platforms will allow separation and re-injection of 95% of produced water. The 5% of water remaining in oil requires separation and treatment onshore when it arrives in the pipeline with the oil and gas (BP 2006b). The oil coming from all offshore platforms is partially stabilized and at the Terminal passes the stage of three-phase preliminary separation (oil, gas and water). After this preliminary treatment the gas is sent to the Gas Compression System, while the water is sent to the Produced Water Storage Tanks. The stabilized and treated oil, free of gas and water, can then be pumped into existing pipelines (BTC, WREP, NREP) through the Crude Oil Storage (Ahmad 2008).

Until the long term produced water project is delivered in early 2009 (as detailed in section 6.1.2) Sangachal terminal is required to support interim management options for produced water disposal onshore. After onshore separation approximately a portion of produced water remains in the oil and is exported with the oil in the BTC pipeline. The remaining volume requires to be disposed of. A portion of this is trucked to a cement plant where it is used in their clinker production process. Any additional produced water that leaves Sangachal terminal for disposal must first be treated to water quality specifications associated with the reuse in cement clinker production and enhanced oil recovery at a third party operated onshore injection location. Sangachal terminal installed filtration units in 2007 in order to meet theses requested specifications. When produced water storage capacities are exceeded and the off site disposal locations are not available e.g. poor filtration unit performance failing to meet specification, excess produced water is filtered and discharged to the lined storage ponds located within Sangachal terminal.

Due to the different commercial agreements for ACG and SD this PW is managed separately and will not be managed by the long term ACG produced water disposal project. Instead the long term disposal of SD PW will be reused for enhanced oil recovery at a third party onshore oil field. This stream also has the contingency option of pond storage during times when the reuse option is unavailable. Currently all daily volume of SD produced water are required to be stored in an on site lined pond.

The management of open drain system waters is less complicated due to the less contaminated nature and smaller seasonal amounts of this wastewater stream. At the operational facilities of the Sangachal Terminal, there is a potential to get contaminated run-off containing oil and/or chemicals in certain process and utilities areas. These areas are kerbed to provide bunding for rainwater (which will also wash any contaminants in the area) to collect in contaminated open drain sumps. This system is designed so that in the period of heavy rain the water will overflow while the contaminated oily water will remain in the sump. Within the ACG site rain water accumulates in the sumps and from here will be directed to an Open Drains Holding Tank. Water in the tank will be taken off site by trucks for treatment and disposal.

SD open drains have less potential for oil contamination but also have gravity separators to separate oil from water. The water is then allowed to flow through charcoal filters to the storm drainage channel. In addition oil in water analyzers are linked to the Control room to ensure water discharged does not exceed the discharge limit of 10 mg/l (BP ST 2007).

5.2.1 Sources and Volumes of Produced Water

The estimated peak amount of PW sent to Sangachal Terminal from ACG platforms will be 59,000 barrel of water per day (bwpd) in 2010 (BP 2006b). Volumes associated with the current operations will decline after that. The main source of the PW is ACG oil platforms, while Shah Deniz gas field are predicted to generate less produced water, maximum rate 2,650 bwpd. Even at its peak Shad Deniz PW levels will not contribute more that 5% of the total stream of produced water. Currently the maximum rate of PW received at the Sangachal Terminal is estimated as 20,000 bwpd. The capacity available with the interim management filtration facilities can manage predicted volumes until the long-term project is ready for larger volumes in early 2009.

5.2.2 Composition of ACG/Shah Deniz Platforms Produced Water

The possible composition of PW was described in detail in sections 4.5.1 and as it was noted there the PW can have different composition of substances due to the nature of reservoir and its geological formation. In the same chapter 4.5.1 table 2 provides information on the typical composition of produced water originated from the Caspian Sea.

The PW composition from oil and gas reservoirs is different in many aspects not only in the volumes of the water generated. Usually PW from gas reservoirs has higher levels of phenols and aromatic hydrocarbons. At the same time the level of salinity in gas fields is considerably lower. The salt content of the produced water from ACG fields ranges from 16,500 mg/l to 40,000 mg/l (URS 2002). Produced water generated at the Caspian Sea fields typically contains such cations as copper, lead, mercury, cadmium and anions such as bicarbonate, bromide, chloride.

5.2.3 Odor of the ACG Produced Water

In addition to chemical composition of produced water representing different concerns another issue, which is worth mentioning here is an odor of the ACG and SD produced water. This odor can be reduced in the produced water after chemical treatment. People working in the vicinity of the evaporation ponds are complaining about the odor, saying that it causes nuisance. Experience gained during the site visit to the evaporation pond, identified that the produced water smells specifically and the odor remains for a long time on the clothes and skin.

The odor trials have been conducted by BP to test the odor by comparing treated produced water and untreated produced water to determine the nuisance levels of the odor. For the purposes of the study two trial ponds were installed which were filled with untreated and treated PW (BP 2008). Majority of people participating in the experiment noted that raw produced has stronger and more offensive smell. That can be explained by the treatment process during which volatile fatty acids are removed, which are partially responsible for the odor element in the produced water. It was also determined by the odor experiment project that the distance at which the smell causes nuisance, is less for treated produced water (10 meter), and more for raw produced water (30 meters). It means that people have to be at 10-meter distance close to the evaporation pond with treated produced water, to feel the smell. In case of untreated produced water the smell causes nuisance already at 30-meter distance. The chemical analysis conducted in the laboratory demonstrated that in the process of treatment the amount of volatile fatty acids in the water had reduced considerably. As it was pointed out by BP Sangacal Terminal Engineer (Sumnar pers.comm) the produced water coming from different platforms has different odor. It was identified that Chirag platform produced water is the most “smelly” one due to the valeric acids being in the composition of Chirag platform PW. Central Azeri platform PW does not have such an odor.

A small-scale odor trial carried out at the ST during data collection allowed first hand experience of the produced water odor. Again, like in the studies described above, most of the respondents (80%) indicated that the untreated produced water is smellier. When the rest (20%) of respondents, including myself, demonstrated more tolerance to the untreated produced water smell. Untreated produced water has a smell of oil, which is very strong and implies harmful impacts on the environment and people’s health. While treated produced water already does not have this “oily” smell, after passing the different stages of treatment but it smells the chemicals, which are added at the second stage of produced water treatment, which is also very strong and may cause nuisance to people.

5.2.4 Sources and Volumes of Open Drain Water

The Sangachal Terminal facilities have the drainage system used for collecting the contaminated rainwater from the processing areas with potential oil and chemical content. The design and operation of the Open drain system for ACG and SD are described in section 6.2. These systems are made to collect the water generated from the heavy rainstorms with the 75mm/h-rain fall.

In some circumstances the Open Drain water may contain chemicals, which are being used at the Terminal such as for example, methanol, corrosion inhibitor etc. Usually the facilitates using the chemicals are located on the concrete bunded areas, so in case of spill the bund is constructed to keep this water, so in normal operating circumstances the chemicals should not enter the open drain systems.

It is possible for contaminated open drain water to contain the following constituents: Dispersed Oil, Residual Chlorine, Sulphide, Phenol, Cadmium, Lead, Mercury, Chromium and Ammonia, Nickel.

On the site the parameters for the amount of these and other constituent in the open drain water are regulated by the special procedure and are monitored through laboratory analysis before discharge.

It is difficult to exactly predict the composition and volume of open drain waters due to the nature of their generation process. Table 7 is taken from the Sangachal Terminal Open Drains Treatment Methods Study Package (BP 2007), this indicates the composition and analysis results for the open drain water, but these data can be considered only as an example of possible constituents:

Table 7: Chemical Analysis of Open Drain waters

pH	7.76
BOD-5 mg/l	18.3
COD mg/l	23
TSS mg/l	10
Oil & Grease	2.7
Chlorine	<0.02
Sulphide mg/l	0.02
Total Phenols	0.003
Arsenic mg/l	<0.001
Cadmium mg/l	<0.001
Chromium mg/l	0.02
Lead mg/l	<0.001
Mercury mg/l	<0.001
Nickel mg/l	<0.001
Selenium mg/l	<0.001
Zink mg/l	<0.001

Source: AIOC ACG Open Drains Conceptual Study 2007

As described in section 6.2 the ACG system will take open drains water from the tank and dispose at an appropriate treatment facility based on sample analysis. The current SD system is under review for upgrade as the charcoals can only remove oil from the water, but not chemicals. There are a number of technological aspects for treatment of open drain water, which are discussed separately in the next chapters.

5.3 Treatment Methods Currently Used by BP AzSPU

5.3.1 Produced Water Treatment Methods

Data gathering during the Sangachal terminal visit included a site visit to the Filtration units. There are two wastewater treatment units (unit 1 and unit 2) installed at the Sangachal Terminal, with the combined capacity of 15,000 bwpd. After the treatment the produced water is loaded to road tankers using the pumps and hoses and then transported to the designated off site disposal locations or to the storage ponds as a contingency option. The treatment units operations and water quality are monitored by the Sangachal Terminal Operations team. The unit is operated by a local company during the site visit their employees also stressed the odor component of the produced water and explained it by the chemical constituents of the produced water. Overall, the odor on the unit was mostly of chlorine nature (chlorine is added at the last stage of the operation).

The information about the process of wastewater treatment units was described in different Technical documents of BP AzSPU and addition clarifications on the process were gained in the course of interview with process unit operators.
Produced water from the Storage Tanks is pumped through special filter, consisting of Walnut Shell Media to the treatment units. Oil is removed at this stage and transferred to the liquid waste tank for further re-use or disposal.

The first stage of treatment of oil-free produced water is performed in the raw tank, where the special chemicals are added to control pH level and protect the membranes from sticking. The typical chemicals added are pH adjustor, anti-scalant and membrane cleaners. After this the water is processed to the second stage, where the system of Ultra-filtration is applied to remove Suspended Solids and small organic substances. One of the units also has a third stage of filtration of Reverse Osmosis to remove Total Dissolves Solids (TDS). The resulting filtered produced water stream is sent to the "product tank" which is equipped with special oxygen sensors. From the product tank, the produced water will be pumped to tankers and sent to the required disposal route. Wastes are removed form the UF and RO filters by back flushing with product water and this is sent to a liquid waste tank. RO unit is not used currently at the water treatment operations, due to the fact that the quality of the water specification required for onshore reinjection for enhanced oil recovery can be achieved even without using the RO membrane technology e.g. the TDS specification is 15,000 mg/l however the RO removes TDS to 9,000 mg/l (BP ST 2007).

The long term produced water project for onshore treatment and running of the produced water through the pipeline for re-injection is required to manage the increased volumes of produced water greater than 20,000bwpd. A 14 inch diameter, 189 long PW pipeline running from Sangachal Terminal to Central Azeri platform Compression and Water-injection Platform has been constructed. The system is planned initially to inject dearated seawater into the well, with later priority given to treated produced water after the construction of the pipeline. This treated produced water from onshore will be a small portion of the overall reinjection water which is also composed of offshore produced water and seawater.

The produced water managed during the long-term project will be treated at the terminal before being sent to the offshore platform. The quality of the treatment should be carefully controlled so thus to avoid corrosion of the pipeline. PW will be initially treated, then transferred to the Produced Water Tanks, then filtered and treated in the new onshore treatment facilities which are now being constructed. These include media and guard filters and dissolve gas floatation. After these processes the water will be pumped into the newly constructed pipeline. In the frameworks of the same project the additional PW tank will be installed with the overall capacity of 130,000 bbl and some other equipment to be involved in the process of water treatment, pumping, pipeline cleaning etc. [AIOC Newsletter 2008]. To eliminate the possibility of corrosion the system of pigging the pipeline and chemical injection will be used.

5.3.2 Open Drain Treatment Methods

As mentioned earlier, currently the system of open drain water is performed by gravity separation of oil and chemicals with the consequent passing through charcoal filters. The system is divided into 8 area sumps, which collect the water from each production areas: ACG Phase 1 production are; ACG Phase 2 and 3 production area; Oil Export area; Oil Storage Area; Pig Receiver area; Produced water area and Open drain area. The system is designed so these different pumping devices control the flow rate at each stream. The system is designed so that in unfavorable circumstances if the water level in the open drain tank becomes high, the contaminated untreated water may overflow to the drainage system. The manual control system is applied to control the rate of effluent outflow. Samples of water are taken and delivered to the laboratory for assessment of water quality before discharge to the drainage system. Valve change over is performed manually.

5.4 Environmental Issues related to Produced and Open Drain Waters and how BP deals with them

BP has well-developed Health, Safety and Environmental (HSE) policies to mitigate and manage risks associated with the oil industry. BP's global operations follow the policy of "no accidents, no harm to people and no damage to the environment" (BP HSE Policy 2007). On site HSE management at Sangachal Terminal is managed by the HSE team, which is comprised of specialists within each element. BP Environmental specialist at the terminal introduced the facility during the data gathering and explained the main activities of their department. Like the majority of BP operates sites globally, Sangachal terminal is ISO 14001 certified and therefore requires that the site operations are managed by an Environmental Management System (EMS). The EMS requires that operational activities are assessed to identify associated environmental aspects and their impacts and put in place appropriate measures to remove or mitigate these. The responsibilities of the staff within the Environmental team is to provide operational support to manage activities associated with environmental impacts e.g. solid and liquid waste disposal, emissions reporting and spill prevention. Periodic monitoring is also performed by the environment Team, e.g. noise and ambient air monitoring (at pre-defined receptors). The EMS effectiveness is enhanced by regular site environmental inspections conducted to control and assess work activities and ensure staff and contractors understand the requirements of the EMS and carry out their work in the correct manner e.g. correct chemical storage, use of portable bunds, spill reporting. Data collected by the environment team is reported internally (to BP Group) and externally Ministry for Ecology and Natural Resources (MENR) as required by operational legal commitments.

5.4.1 Monitoring Activities performed by BP AzSPU

BP AzSPU is conducting different environmental and ecological monitoring in Azerbaijan. In 2005 the Integrated Environmental Monitoring Program was implemented in Azerbaijan. The program involves the development of different studies, monitoring activities and reporting. The monitoring of marine ecosystem was recently conducted near with the BP platforms offshore and Sangachal Terminal. During the monitoring process the special attention is devoted to the discharge of drilling muds into the sea. Another aspect of the monitoring program involves the surveys of surface and groundwater monitoring in the vicinity of pumping and pigging stations operated by the company. The effluent discharges are monitored at all the sites. (BP 2006a)

Monitoring of the produced water is performed in accordance with the requirements of BP Integrated Environmental Monitoring Plan and is conducted to ensure the process of project implementation and identify the gaps or areas for improvement. The special sampling regime was developed by the Company for the continuos checking of the quality of the treated water and the requirements for chemical addition. The sampling and analysis is performed by the onsite laboratory technicians. This company conduct sampling in accordance with the existing sampling technique and for that purposes the treated PW, raw PW and waste water tank water is being sampled and analyzed. In sampling practices the company is following the Standard Practice for Petroleum and Petroleum Products (D 4057-95 1997). This standards describes the methodology of sampling, sampling containers to be used, sample handling and methods of sampling from tankers, pipes, drums etc.

For the purposes of wastewater discharges to the environment the company follows the combined parameters introduced by World Bank, EBRD and European Union. The maximum allowable limit standards for the discharge parameters are presented in Table 8.

Table 8: Effluent Discharge Standards

pH	6.9
BOD_5	25
COD	150
TSS	20-30
Oil & Grease	19 mg/l (daily)
Residual Chlorine	0.2
Phenol	1
Sulphide	0.35
Total Toxic Metals	3
Cadmium	0.1
Chromium	0.5
Copper	0.5
Lead	0.1
Mercury	0.01
Nickel	0.5
Silver	0.5
Zink	2
Ammonia	10
Total Coliform	<400 mpn per 100ml
Source: BP ACG PWD ESIA 2007	

The monitoring and laboratory analyses are kept at the ST with the Environmental Team. On review it was noted that the laboratory results of the treated water conducted in April 2008 demonstrate that Total Suspended Solids (TSS) and Chloride ions concentration exceed the limits in Table 8 and therefore would not be suitable for discharge to the environment. Some activities to identify the reason of that water quality were conducted in order to find the proper solution.

The research activities conducted at BP AzSPU facilities allowed gathering information, which will constitute the base for the case study. This case will be individually analyzed in the discussion chapter, with the comparison analysis provided with the second case study. The data collected will help to base “the ground” for the theory of this research, a strategy applied for research doing (Punch 1998).

Chapter 6: Produced Water: SOCAR Case Study

6.1 SOCAR facilities

During the research trip to Baku, Azerbaijan, the access to SOCAR facilities was not granted and this part of the work was prepared based on different articles and publications and personal communication.

State Oil Corporation of Azerbaijan Republic (SOCAR) is responsible for oil and gas production in Azerbaijan. In 2003 all Onshore and Offshore developments were transferred to SOCAR by Presidential decree (APS 2004). It is running two oil refinery factories, responsible for pipeline system in the country and is actively involved in oil production activities. SOCAR possesses 78 extraction fields onshore and offshore (APS 2004).

6.1.1 Offshore facilities

The main oil production comes from the offshore fields. There are 35 offshore fields operated by SOCAR in the Caspian Sea, 17 from which produce 80% of all SOCAR's production in the region. The majority of the fields are located on the 200-meter depth of the sea. Such offshore fields as Oily Rocks, Bahar, Zira and Shallow Water Guneshli are the main offshore fields contributing considerably to the production rates. The Guneshli is the giant oil field on the Caspian Sea. SOCAR is developing its shallow part. The most of the offshore fields were discovered in the Soviet times by Soviet geologists. Oily Rocks is one of the oldest offshore oil fields belonging to SOCAR. It was one of the huge complexes, constructed in the sea, where there are different facilities, hospital, camps for workers etc. Now the field is considerably depleted and production rates are not considerable. The complex is more and more filled with water and is falling apart threatening the environment of the Caspian Sea (APS 2004).

6.1.2 Onshore facilities

Some part of oil production comes from oil fields located onshore on the Apsheron peninsula (SOCAR 2008). 36 from 42 available onshore oil fields are operational now. Some of the onshore fields are about 100 years old. Balahani and Sbunchi being the oldest among them are huge fields producing oil till now (annually 750,000 ton). There are 9,000 oil wells on the Apsheron peninsula, 50% of which remain non-operational. They are old and require renovation. Some of the onshore fields have the oil reserves but the technology and investments are required for its extraction.

6.2 Overview of SOCAR Waste Management System

This overview was prepared based on the data provided by SOCAR. As it was mentioned earlier in the Limitation Section, the data provided is scarce and due to that fact the detailed overview of the SOCAR waste management system cannot be presented here.

SOCAR is a post-Soviet Company and as in many such companies involved in oil and gas development the waste management was not performed on the proper level (UN 2004). For many years of oil and gas extraction huge volumes of produced water, drilling muds, sewage were being discharged into the Caspian Sea (UN 2004). At the moment SOCAR is responsible for the past failures of waste management system and has to develop new strategies to overcome the existing problems. This requires serious financial investments, improvement in maintenance of available equipment and establishment of clear aims and mitigation measures. At the moment the waste management system is in the stage of development. The lack of proper management currently can be observed at SOCAR operational sites, not far away from Baku, country capital. The environmental safeguards are completely lacking in the production sites of SOCAR (UN 2004).

According to SOCAR, currently their onshore and offshore facilities do not discharge harmful wastewater onto the ground and surface waters. But at the same time, during the past period there was not any considerable modernization made in the existing equipment (UN 2004).

The information available implies the considerable steps to improve the current state of the waste management system and the development of the new waste management strategy.

6.2.1 Source and volumes SOCAR produced water

It was almost impossible to find out about the volumes of the water produced during oil extraction, treated and discharged by SOCAR. This information is not available officially. Some data is mentioned in the informal interviews and in some publications, but it is very difficult to decide how reliable this information is.

As it was mentioned by one of the representatives of the Azerbaijan State Oil Scientific Research and Project Institute in an interview to Media Press agency, annually 350 million tones of produced water are discharged into the sea by SOCAR (ASOSRPI 2007).

The volume of the produced water extracted by SOCAR from all the oil fields is 20-25 times the oil. As it was mentioned by the same representative of the Azerbaijan State Oil Scientific Research and Project Institute in an interview, the price of all constituents in the produced water contained in one ton of oil extracted equals USD 257/ton on the world market. The constituents of produced water included 10 minerals, such as sodium, chloride, magnesium etc. In the produced water discharged by SOCAR annually there is 2 million tons of sodium chloride, which is imported to Azerbaijan from nearby countries. The research conducted by the scientists from the Institute indicate that there is a possibility to treat the produced water to the level when these constituent can be extracted and further re-used. In addition, the Institute representative stated that, treatment technologies that can remove these constituents from the produced water are available in Azerbaijan. The investments are required for the projects to be implemented.

6.3 Treatment Methods Currently Used by SOCAR

The technologies used by SOCAR are mainly based on the preliminary water separation and gravity system. The treatment technologies and equipment is quite old.

The oil is directed to the special facilities where it is separated from water and gas. Most part of treated water is sent for the re-use in some technological processes, the other part is re-injected into the well, and the remaining part of it is being sent to the treatment facility (SOCAR 2007). One of the wastewater treatment plants available in Baku is using biological treatment process for the wastewater treatment. Its capacity is 640,000 m^3 per day, but it is not working at full capacity. Abrupt fluctuations of the treated water cause the problems with the units' operability. According to Abilov, the main problems with the environment on the Apsheron peninsula is the oil polluted land and poor wastewater treatment facilities. (Abilov 2005).

Another treatment plant available in Azerbaijan (Baku) uses mechanical treatment methods. It is used by Azneftyag oil refinery for its wastewater treatment (2000m3/hr). Sand catchers are used to separate sand and other solids from the water. The separation process starts from Oil Catchers Unit. At the second stage flotation method is used. The sludge, which is generated in the process of treatment, is processed by oil sludge shaker. The steam produced at the sludge shaker is used for other stages of treatment units.

As was stated by SOCAR representatives (informal interview), there are a lot of requirements the company is applying for the projects on oil and gas extraction. One of these requirements is the treatment of oil, gas and produced water in the production units to the conditions corresponding to the market requirement.

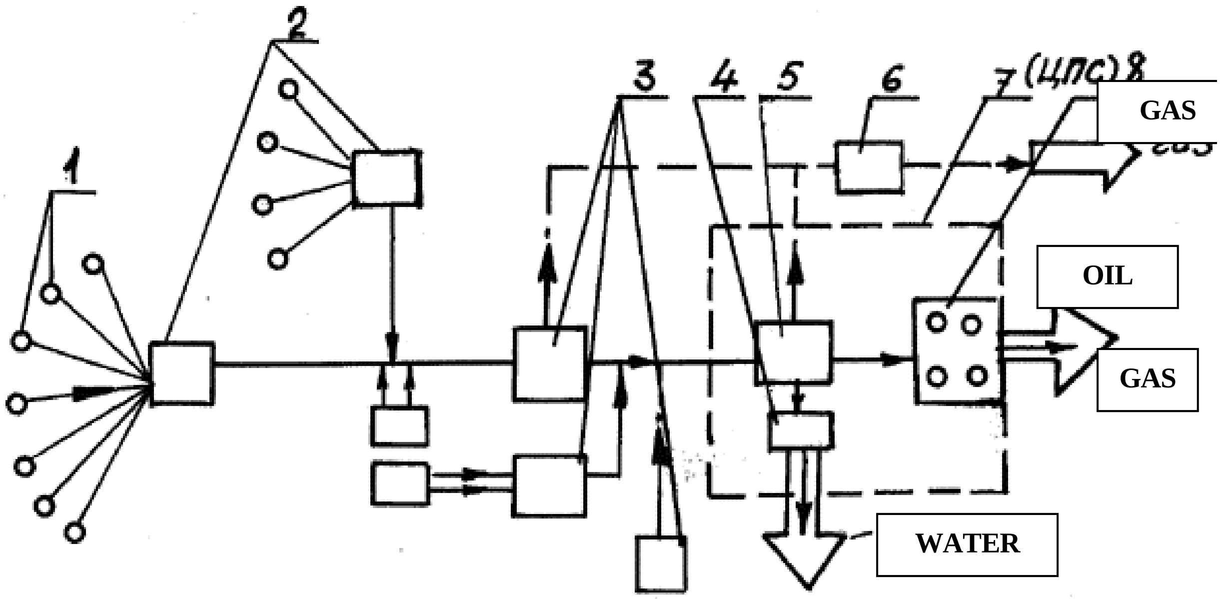
The produced water is transferred to the compressing wells of the same or other oil fields, in order to re-inject it into the well for the well pressure stabilizing purposes.

The most of the SOCAR offshore and onshore produced water is re-injected into the wells. The process of onshore water re-injection used by SOCAR is based on the maximum removal of oil from the water and its further re-injection into the well through compressors or specially drilled absorbing wells (Salimov 2008). The process of the onshore re-injection described by Salimov has the following stages and processes. The onshore technologies usually include preliminary oil-gas-water separators, primary treatment removing the small particles of oil from the water and mechanical filters. The main aspect after the produced water re-injection is to avoid its contact with the water being extracted for industrial purposes. The technological decisions suggest re-injecting the produced water into the non-productive well, not being the part of the extraction wells layer. As SOCAR representatives informed in an unofficial interview (unofficial pers.comm) the wells for re-injection are selected by the SOCAR Department of Geology. The process regime used in the re-injection operation can be performed by cyclical stages of injection and stoppage. The interesting fact about the cyclical process is the “natural flow” process of the main part of the well occurring during the period of stoppage. Some part of the water constituents introduced to the well earlier, will be carried to the catchment part of the well. During the long period of stoppage there are conditions created in the well in which mechanical mixtures, such as iron sulfate and its other associates with hydrocarbon have the density lower that that of water and as a result they form sediment. At the same time the flotation of the hydrocarbon particles, which are with lower density than water take place. Overall, during the stoppage of the injection process, the processes of bottom and interim layers formation take place, which are similar to those happening in processing reservoirs. Salimov, states that during the re-injection processes of onshore produced water, the processes that are originate in the well, with stoppage phases, can be possible technological solution for the PW constituents removal. Salimov’s studies conducted for SOCAR state that this solution becomes possible if the wells are drilled with the special inclined method. In this case all the technological equipment, including pumping stations, treatment unit can be compactly located in one block.

When SOCAR has a group of oil fields, a centralized system of oil collection and preparation is used. That means that the volume of group wells production is collected in a Combined Automatic Unit (Diagram 4). The product coming to this unit is oil with gas and water. After the separation of oil and gas and water, the oil still contains produced water. This produced water in oil constituent goes to the Central Collecting Point. The removal of water at this stage is complicated due to the fact that oil and water constitute stable emulsions. The water is dispersed in oil in small drops. To remove the water and salt at this stage the gravity method, thermo-chemical methods, electrical desalination or de-watering methods are used. SOCAR usually uses gravity methods (unofficial pers.comm). During the gravity methods coagulation of water drops occurs and heavy drops under the gravity law go to the bottom of reservoir. The gravity method usually takes 48 hours or more and is a low efficiency process. Chemical and thermo-chemical separation of water from oil is a more effective process. The produced water coming from the process of separation contains the high level of hydrocarbons, salts, iron, which can block the productive well. Each oil field can have its own requirements for the amount of the mechanical constituents. In most cases this water is re-injected into the depleted wells.

There are a lot of new projects developed by different research institutions related to the wastewater treatment, but unfortunately most of them are not implemented. One of the technologies was researched by F. Abilov, who thinks that optimization of treatment process can be achieved by efficient bunding control and the robust system of its monitoring (Abilov *et al* 2005) The technology developed by Azerbaijan Water and Wastewater research institute is based on the automatic laser analyzer for the oil content detection in the wastewater. The system of automatic analyzers providing opportunity to detect the oil content and oxygen of the treated water, by authors opinion, will help to conduct wastewater treatment more efficiently.

Figure 1: Complex Oil Preparation Unit



1 – is oil well; 2 – automatic measurement equipment; 3 – pumping unit; 4 – produced water removal unit; 5 – oil preparation unit; 6 – gas compressing station; 7 – central point of water, gas and oil collection; 8 – reservoir park

Source: Oil, Gas and Fund Market web-site http://www.ngfr.ru/ngd.html?neft18 (consulted 10 July 2008)

According to Abilov (2005), laboratory analysis on the content of oil in the water cannot be treated as reliable due to the fact that there is not now the clear definition of oil and oil products used by laboratories. In this respect there are 20 analytical methods that can be used and there are great discrepancies between these analyses.

6.4 Environmental Aspects related to SOCAR Produced Waters and how SOCAR deals with them

As it is mentioned in different publications and reports, official and unofficial, local and international, the impacts of the oil and gas production on the environment of the Caspian Sea and Apsheron peninsula are considerable and become more and more threatening. I have reviewed a lot of publications on that subject most of which are by independent scholars and researchers, NGOs and the information that has been collected from these sources can be summarized below.

The ecologists from the local environmental NGOs are very concerned about the current ecological situation and level of pollution in the region. (Echo 2007). They state that the situation with oil spills, produced water discharges, air pollution on Apsheron peninsula is threatening the health of people. One of the ecological concerns is the land contaminated with the produced water. This water contains radio-nuclides, which are dangerous for human health. At the places of the oil extraction on the Apsheron peninsula produced waters formed the contaminated lakes, ponds or lagoons.

Some of these extraction fields are depleted and abandoned now and people build their houses near with these contaminated lands not realizing the risk associated with this "neighborhood". The water remaining on these lands for many years may cause ground water contamination. The vegetation, biodiversity and humans are highly affected by the contamination by oil and oily products. The level of radiation on the peninsula is very high (400-1200 gamma-dose/hour, compared with acceptable standard of 15-25 gamma-dose/hour) (UN 2004). The health problems among population are increasing exponentially. According to Ibrahimkhalilova (Echo 2007), SOCAR is not implementing any considerable measures to improve the situation with soil and water contamination.

According to the Ministry of Ecology and Natural Resources the total area of the land contaminated with produced water is 10, 000 ha [Caspian Energy 2008?]. Some of the lands SOCAR inherited from the Soviet times of oil extraction and just continued their contamination. The necessity of the clean-up measures on the contaminated lands is recognized by the Ministry of Environment (MENR) and SOCAR. Unfortunately, the present technologies applied by SOCAR for gas and oil extraction cannot eliminate the negative environmental impacts (Effendiyeva 2000).

In an interview with Interfax Azerbaijan on 23 June 2008 Mukhtar Babayev, Environmental Vice-President of SOCAR (Interfax 2008), stated that one of the most prominent ecological problems the Company is facing today is the artificial oil "lakes" and puddles contaminated with produced water and oily products. Among the measure which the company is going to implement M. Babayev (Interfax 2008) mentioned the modernization and refurbishment of the outdated wells and the removal of unused equipment from the offshore fields. He also stated that bioremediation technologies will be used to rehabilitate oil-contaminated land. SOCAR will deal with this problem in cooperation with the World Bank, Deutch Bank and Korean Agency for International Cooperation.

The overall situation with the pollution in the region is very complicated requiring huge financial investments and efforts from the MENR, SOCAR, local NGOs, and public. The picture provided below is just one of the many available on the SOCAR official web-site which can in some extent illustrate the situation with the produced water contaminated SOCAR production sites on the peninsula.

Picture: **SOCAR Onshore Operational Site**

Source: SOCAR Official web-site: http://www.socareco.az/012ru.php

According to Babayev (Interfax 2008) ecological problems and environmental management are nowadays SOCAR priorities. The rehabilitation of contaminated land on the Apsheron peninsula is the short term environmental program to be implemented by the Company. Recently the World Bank approved three projects for the improvement of ecological situation on the Apsheron peninsula (WB 2008). One of the three projects is rehabilitation of oil contaminated land from onshore oil production. In accordance with the Worlds Bank data (WB 2008) 30,000 ha of land are contaminated with oil and require rehabilitation and clean-up. The total amount of the grant approved for three projects is USD 164 million. SOCAR will be responsible for the implementation of the project. The pilot land plots were detected and the trials for bioremediation treatment technology have been conducted with the participation of the Academy of Science. The contaminated wastewater and sand are collected by trucks and transported to the treatment units.

6.4.1 Monitoring Activities Performed by SOCAR

Monitoring activities of the offshore oil and gas production are performed by the Company in accordance with the standard named Rules for quality control of seawater (GOST 17.1.3.08-82). The standard was prepared in Soviet times and is out of date. Control Inspectorate of the MENR performs regular monitoring and inspection of the offshore facilities. In accordance with this Inspectorate it is stated with the reference to the MENR that currently there are no leaks or discharges performed by the offshore facilities belonging to SOCAR (UN 2004).

There is no data available on the frequency of the monitoring performed by SOCAR, the objects of monitoring and people involved in that process.

Chapter 7: Assessment of Produced Water and Open Drain Wastewater Treatment in Oil Industry of Azerbaijan

Water is the largest waste stream generated by Oil Industry in the process of oil production. There are estimates which show that annual worldwide water production by Oil and Gas Industries is about 77 billion barrel. While annually worldwide oil production is 30 billion barrel. (Moritis 2007).

Produced water is a by-product of oil and gas production. It is very difficult to manage this wastewater stream due to its volumes and variability. (Benko and Drewes 2008). The quality of produced water is determined by organic and inorganic components and depends on geographic location, geological formation of the field and type of hydrocarbon being extracted. Usually the volumes of the produced water tend to increase during the lifetime of the well.

Open drain water on the oil industry onshore and offshore sites involved in oil handling and production processes is another waste stream generated by the contaminated run-off, which may contain the oil and other hazardous products used on the site. The volumes of open drain water cannot be compared with those of produced water. But proper management and treatment of open drain water should be ensured as well, as if this wastewater stream enters the local drainage system it may cause problems for environment and people's health.

BP produces water as a by-product at ACG and Shah Deniz offshore fields. By the Company estimated the volume of produced water generated by oil production will peak by 2010. SOCAR as well generates considerable volumes of water, both onshore and offshore.

The ecological situation on the Caspian Sea and on Apsheron peninsula raises concern among ecologists, researchers, NGOs and local people. The proper management of the oil industry generated wastewater streams can improve the situation and ensure sustainable development of Oil and Gas Industry.

Following the main objectives of the current work the focus of this discussion section will be concentrated on the following issues:

- the technologies available for the oil industry wastewater treatment, their advantages and disadvantages
- the technologies available worldwide and their applicability to the Azerbaijan Oil Industry generated wastewater streams
- the existing legislative framework for the management and controlling the risks related to the discharges of wastewater into environment
- potential future solutions for the wastewater management and treatment based on the existing practices worldwide.

7.1 Comparison of Technologies and Management Approaches used for Wastewater Treatment in Azerbaijan Oil Industry

Nowadays the technologies exist for the treatment of produced water to the different purification levels depending on the disposal routes of the wastewater. Initially, to understand the situation with the produced water treatment and management in Azerbaijan on the example of two case studies, the comparison of the technologies used has been conducted.

BP is not discharging any oily wastewater into the Caspian Sea, following the Law of the Azerbaijan Republic (Environmental Law 1984) prohibiting such discharges. The company produces oil from the offshore fields on the Caspian Sea, no onshore production is conducted. The company in its operations with wastewater takes into accounts the volumes and possible routes for the disposal of produced water. From the technological point of view, BP is using 5% concept, in accordance with which the technologies available on the offshore platforms are capable to remove 95% of water from the oil for its further re-injection into the well. BP is following special requirements, which control the quality of the water used for re-injection. Furthermore, the company carefully controls the quality of the water used for re-injection due to the fact, that some constituents in it, if not treated properly, can cause problems with the oil reservoir and sometimes its plugging. The main concern and environmental risk is this 5% of water contained in oil. The system of treatment installed on the terminal facility consists of two units and is based on membrane technology. The design of treatment facilities includes pumps, filters, raw, treated and waste tanks and UF and RO membranes. The technology is based on the 3 stage treatment process. The walnut filters used at the primary stage of the treatment separate oil droplets up to 100μ. In the second stage 15-20μ oil droplets are removed from the water. While in the third stage the UF filtration is used as the “polishing” treatment. The system corresponds to the international standards. The treated water ideally, is intended for re-injection into the onshore well or used in the cement clinker production. Although, the units have the failures sometimes what makes the treated water not usable for the re-injection purposes. The reason for those failures is being investigated. Potentially it can be caused by the mixing of produced water from different production fields or the membranes blockages or some other reason. The RO membranes initially designed in the treatment unit and involved in TDS removal are not used currently, due to the fact that the quality corresponding to the intended use of the water can be achieved without involving RO mechanism. Probably during the implementation of the long-term project, when the treatment system will be redesigned the RO will be used in the “polishing” stage of the treatment.

Currently in the periods of treatment units’ functions failure, the produced water cannot be sent for the re-injection to onshore well and only can be used in the cement clinker production. The current contingency plan for this water is its discharge to evaporation ponds, available on site. The evaporation ponds are designed with special protection layers to avoid contamination of soil and groundwater. The usage of evaporation ponds is not always viable, as there a lot of potential negative impacts related to it (BP 2006). The sludge that is formed in the pond is a hazardous waste and should be properly disposed of. Moreover, evaporation ponds may cause some adverse effects on the biodiversity and wildlife (especially birds) moslty due to high salinity of the produced water. In addition, the odour of the produced water is very pungent and causes nuisance to people working in close vicinity to it. BP is dealing with odour issue of the produced water and has conducted studies and queries about the produced water odour issue and in accordance with the outcomes it was stated that the pond is located at the distance, at which the nuisance to the working force is minimal. The terminal itself is located in the place open to all the wind, and the weather in Baku usually is windy, so from that perspectives, the odour issue can potentially cause nuisance to people. At the same time, the windy weathers are positive feature for the evaporation processes. In case of high storm, there is also a potential issue with water leakage from the evaporation pond.

Currently, this decision with the evaporations ponds in case of treatment failures is the only feasible contingency plan for this volume of water, as it cannot be kept in produced water tanks, as it may cause changing the quality of the water and will make the further treatment more complicated. Moreover, if the unit failure continues for some period the capacity of the produced water tanks will be not enough to accommodate all the volumes of coming water. Taking it into account, the only sound short-term solution in this situation was the usage of an evaporation pond. In the long-term perspective the water will not be stored on shore and after the treatment will be sent to the offshore well re-injection. The re-design of the units will be probably required to make sure its proper functioning.

Comparing technologies used by SOCAR and BP is complicated based on the incomparability of old and new equipment. BP is using new technologies for the purification processes while the equipment used by SOCAR is old and primitive (Effendiyeva 2000) and requires considerable improvements. As it was described in the Case study the main method used is gravity separation in which mechanical treatment system is involved. In the interviews company's representatives referred to the existing legislation, where the technological aspects are described and assured that the company is following all the instructions carefully. The gravity separation method can be used only for the separation of larger oil droplets and is not able to treat the chemicals and other constituents in water. The excess of water after re-injection containing sand, oil, chemicals is sent to the treatment plant or for the re-use in the technological processes. Moreover, the gravity method used is a very time consuming and not always effective one for secondary treatment.

There are some treatment plants available in Azerbaijan but some experts call their capacity into question (Abilov 1999).

The World Bank, which is sponsoring the clean-up operations on the Apsheron peninsula SOCAR operational sites has officially announced that 30,000 ha of the land is contaminated with produced water and other oily wastewater discharges. The discharges to the terrestrial ecosystems are difficult to conceal, they are very much visible. In the aquatic ecosystems all the scale of the problem is not realized. The sea is usually considered as the giant sink for all the waste and wastewater. Some representatives of MENR claim that this is the legacy left after the Soviet oil exploitation times, but the equipment used has not had any considerable changes over that time (Abilov 2005).

The comparison of the Open Drain Water technologies used by BP and SOCAR was not conducted due to the absence of such data for SOCAR operational sites.

From the wastewater management point of view BP has more developed system and wastewater strategy if compared with SOCAR. SOCAR is a typical post-Soviet company, using old standards and approaches in its operations. The waste management system of SOCAR requires further development and modifications. BP has developed long-term plans for the produced water disposal option taking into account the predicted volumes of the produced water generation. While SOCAR does not have any studies related to the generation of produced water from the available onshore and offshore facilities. As it was found out during the research most of the SOCAR wells are old and the generation of the produced water will increase with time. It was not possible to find SOCAR documents establishing long-term plans for dealing with the increased volumes of produced water. In addition, there is not consistency in the scale of produced water contaminated SOCAR operational sites. The figures in SOCAR data differ from those of the World Bank. Dealing with the current produced water issues SOCAR should consider the oil contaminated sites left as a legacy from the Soviet times.

In the wastewater management system BP is trying to apply integrated management approaches, which is still requires additional studies and efforts from the company. SOCAR still will have to overcome the challenges currently existing with the contaminated lands and then start developing the new integrated wastewater management approaches in its operations. BP uses international standards in its operation, which are in some instances Best Available Technologies. SOCAR still uses the standards, which are not consistent and do not correspond to the nowadays challenges related to the produced water.

7.2 Review of Technologies Available in Azerbaijan

During the research the review of technologies available on Azerbaijan market was made. Based on that review the advantages and the disadvantages of the technologies in their applicability to the treatment of produced water were summarized (URS 2002). The table provided below (Table 1) includes the brief description of the technology and its advantages and disadvantages based on different criteria. The main criteria used to assess the available technologies are throughput of wastewater stream, treatment technologies, distance from the terminal and generation of hazardous sludge and ways to dispose it. There are a lot of other criteria, which could be used to provide the better assessment results, such as for example, location of the treatment facilities close to the social receptor (odor issue), availability of spill response, availability of permit from MENR and others. But this data was not available and required special research activities.

Table1: The review of Available Technologies

Options	**Criteria for technology review**			
	Treatment Option	***Throughput***	***Road Risk/Distance from Terminal***	***Solid Waste***
A	The process for the treatment of the PW combines mechanical, chemical and biological treatment.	400m3/day is the figure of the throughput which corresponds to the physical area demand.	The transportation will be required although the location of the site is not far away from the terminal. The special trucks are available	There is a potential to treat the oily sludge and recover the crude oil using three-stage decantation system
B	The mechanism used by this technology is based on mechanical and chemical treatment	The volume of sewerage oil-based water, subjects to treatment on new station of purification, makes average 1200m3/per	The site is located at long distance from the terminal. Road risk is high	Sludge are accumulated in vessel and from it is directed to section of dehydration of sludge (centrifuge)
C	The process is based on the conventional water treatment train consisting of gravity separation, chemical treatment and clarifying vessel, filtration and polishing. The usage of media absorption system, which enhances the polishing, stage to achieve the very low oil in water values is the key component of the tertiary treatment.	A feed flow of 2m3/hr	Unknown	Solids collected from the bottom of the Treatment tank and clarifier tank are fed to the peristaltic pump to the Sludge Holding tank. The thickened sludge is them pumped to Filter Press for compaction.
D	MPPE technology is used Can store and process the water. Storage capacity is liquid oily waste from 280 to 50,000 tons. There is a possibility to purify the PW and discharge ecologically neutral purified water to the sea.	Exact throughput is not specified	Not required, can be installed on site	No options suggested
E	Mechanical treatment is used	2600m3/hr	Transportation required for long distance	Oil sludge shaker performs oil sludge processing. Then steam is used for other stages
F	Chemical treatment systems used will allow automatic and instant deviation correction. The recovered condensate/oil will be >99% pure, initially the water will be ,100ppm hydrocarbons and will be further treated to meet the standards required for re-use. All flows are measured by positive displacement metering sensors.	Not specified	Transportation is not required as the equipment can be easily installed at site	No disposal options provided
G	Chemical Treatment – filters-cation and anion exchangers used for additional treatment. total receiving volume for 2 tanks and 1 chemical treatment unit – 160 m3.	300m^3 liquid waste during 24 hours	Transportation involved	No options suggested

Technology A has a lot of advantages, if compared with Technology B, as the process includes a combination of different mechanical, chemical and biological processes and there are also additional options available such as nutrient dosing, chemical oxidation, additional COD removal etc. In addition this technology offers the solution with the treatment of oily sludge, which is recovered from the crude oil using three-stage decantation system which would separate decanter cake, oil and water. While technology B uses mechanical and chemical treatment processes. Initially the gravity method is used to separate oil from water and then the chemical treatment processes achieve the purification level of the water. The capacity of the treatment unit in technology B corresponds to the peak production of the produced water. The combination of different chemicals and their dosage added to the treatment units depend on the quality of the wastewater.

One of the main disadvantages of technology A is the activated carbon adsorption, which will probably be influenced by the salinity concentration of the biological effluent. Safety issue related to the transportation should be considered, as transportation of produced water will be required although not for the long distances. While for the technology B the important disadvantage is its long-distance location from the main produced water generation sites as the transportation of the produced water by the highway is involved.

Technology C is similar to technology B and also uses mechanical and chemical methods of treatment. In addition the special filtration system is offered to remove residual dispersed and dissolved hydrocarbons to very low levels. The generation of hazardous sludge is the main issue with technology C.

MPPE (described in Chapter 4.6.4) has a lot of advantages if compared with technology A, B and C. Almost 100% pure hydrocarbon phase is recovered, removed from the system and left ready for recycling or disposal. The system is easy to operate. It is flexible, compact, fully automated, remote controllable. No chemicals required apart from the MPPE material that will be locally exchanged. The equipment can be installed at the site and no transpiration will be required. The disadvantages of the MPPE technology if the applicability to BP Case considered is the requirements to install more operational units to treat the required volumes of produced water generated by BP offshore platforms. The generation of hazardous waste is another problem associated with this technology.

Mechanical treatment process is offered by technology D. Sand catchers are used to separate sand and other solids. Then flotation system is used for the secondary treatment. This is a mechanical treatment plant, during the treatment process not all the constituents, which are contained in the produced water can be removed. Open ponds are used for the transferring the wastewater from one stage to another. The odor issue can be a problem. In addition transportation will be involved.

Mechanical and Chemical treatment methods are used by technology F like by in B and C. Majorily transportation of the produced water is not be required as it can be installed at the facility. The disadvantage of the system is the high requirement for manual labor.

The purely chemical treatment is offered by technology G. Polyacrilamide polymer is used as flocculating agent for achieving water clarity. Two vertical chemical fluid receiving tanks, one chemical treatment unit and flotation cell will be used to store and treat the PW. Receiving volume of each tank is $60m^3$; chemical treatment unit is 40m3; total receiving volume for 2 tanks and 1 chemical treatment unit – 160 m3. The main concern is the generation of hazardous waste. Transportation to the treatment unit is involved.

As it can be seen from the described technologies most of them are based on mechanical and chemical treatment, which requires ponds and settlers. The treatment of hydrocarbons, suspended solids and chemicals is the main problem for the treatment facilities. The review of these available technologies is just based on the information and the equipment specifications provided. Trials are required to determine the quality of treated water the technologies can provide.

There are other technologies potentially available in Azerbaijan for the treatment of produced water. One of these technologies is based on the bioremediation process. The reed bed technology is used in many countries. As it was described in Chapter 4.6.2 in the process of bioremediation the hydrocarbons degrade in the course of microbial process. If the required water quality can be achieved it is possible to use this water for irrigation purposes. The disadvantage of this treatment method is area required for the reed beds construction. As it was estimated by BP, 20 ha will be required to treat the produced water from ACG fields. In addition the level of salinity in produced water requires consideration for this treatment technology. Another disadvantage is the usual blockage of the reed bed systems.

The treatment of produced water to the standards, which allow using it for irrigation purposes, is another option. Unfortunately, after the reviewing of the technologies presented in Table 1, it can be stated that neither of it can treat the water to the specific irrigation standards.

Although, there are some studies and technologies, proposed by Azerbaijan technical experts, which potentially can be used for produced water treatment. One of these technologies is proprietary reagent, which can remove calcium and magnesium from the produced water. It also can reduce the hardness of water, not favorable for irrigation purposes. The experts claim that this technology is working without producing a by-product.

Another potential technology is developed for the removal of heavy metals. The Azerbaijan State Oil Academy proposes to use polymeric resin for that purpose. The hardness, however, cannot be removed from the produced water.

Zeolite technology, which is used in US for the treatment of drinking water, is also available in Azerbaijan and can be used for the removal of heavy metals and hardness form the produced water. The recovery of iodine and bromine can be performed by the special treatment available at Iodine plant near Baku. The plant daily capacity is 50,000m^3 of produced water. But in this case the additional treatment for water will be required, as some of the constituents will remain in the produced water after the treatment. All these technologies are not described in details by the institutes and experts and they remain in theoretical prospects. None of them was implemented and in this respect for the purposes of this work it is not possible to provide the full assessment of these technologies.

7.3 Environmental and Health Impacts related to Oil Industry Wastewater

The long history of Azerbaijan oil and gas extraction has left its impact on the environment in the region. The ecological problems of the Caspian Sea have been discussed in many publications and researches. The SOCAR case study also contains information on oil industry wastewater contamination and its impact on environment and human health on the Apsheron peninsula.

Generally the consequences of the intensive oil and gas extraction during Soviet times can be felt nowadays, as the air, soil, water are severely polluted. Environmental experts consider that rehabilitation of oil contaminated lands on the peninsula, management of wastes produced during oil extraction are among the most severe problems. A lot of people living on the lands contaminated with oil wastewater and experience health problems. The hydrogen and sulfur gases evaporating from the oil wastewater ponds can cause different diseases. Sometimes people realise the problem but cannot afford moving to another place. The clean-up operations require financial investments and new technologies.

The environmental problems of the region do not receive the required attention from local mass media, NGOs, activists and citizens. In this respect, public awareness on the problem is low. There are some NGOs working in the area of environment but they do not represent any proper power and cannot influence the situation. In addition they claim the lack of transparency on the environmental issues. In most cases people are unaware of the scale of environmental problems in the country and do not realise the consequences it may have. For example, Sumgait City, industrial centre of Azerbaijan, was a concentration of chemical, petrochemical industry and heavy metal production in Soviet times. Some journalists call the city “environmental nightmare” and claim that 70% of the population in this city suffers from industry discharges related illnesses (Smailes 2001). Now most of the factories are not functioning but the consequences of the severe pollution still has its affect on new generation. There some efforts made by the Government and Environmental Agencies but they are not enough and require more attention and financial support.

Another issue is the absence of scientific background on the scale of environmental problems in Azerbaijan. There are some Scientific Institutes in the country but they do not get proper financial support to conduct the scientific researches on the environmental problems and ecological management issues.

The development of environmental education is another factor that may positively affect the situation with environmental awareness rising. At schools the environmental subjects are not taught, as the system mainly based on the Soviet educational elements. Now some Universities in Azerbaijan started to open ecological departments and environmental issues started to attract more and more young people. (Shelton 2003).

The ecological monitoring activities are not well developed in the country. But some attempts are done in this respect, the new regulations are being developed, environmental issues started to appear in many projects conditions and environmental law become stricter. But law enforcement is another problem in this respect. It also can be mentioned that the cooperation on environmental issues between the countries located on the Caspian Sea is not well developed. Some steps are required in this direction as well.

Nowadays, the foreign companies working in Azerbaijan have a lot of obligations in environmental and health issues. The ESIA for any project is a requirement now. The companies realize the importance of wastes and wastewater treatment and the required steps in this respect are made.

It is interesting to mention that notwithstanding the fact that in PSA the production related wastes and requirements for its management are not mentioned, BP is considering environmental issues and developed waste management strategy, which is one of the main elements of the Environmental Management System of the Company.

Talking about general environmental issues related to the oil industry wastes and wastewater it worth recommending to the governmental agencies to pay more attention to the environmental issues, to developed state program for environmental monitoring. The development of public awareness on the environmental issues is another aspect that requires attention. Active involvement of NGOs and public into the decision making should be promoted.

7.4 Assessment of Environmental Laws and Legislation and Wastewater Management and Treatment in Azerbaijan

The review of existing legislation provided in Chapter 4 gives the general information about the legislative base of the country. The legislative system of Azerbaijan is young. Most of the environmental laws were adopted during 1992 – 1999 time period. Many of the standards related to the oil industry wastes were inherited from the Soviet times. The experts made some changes and revisions to these standards.

As it was discussed in the previous chapter, with reference to the National Environmental Action Plan (NEAP 1998), the law prohibiting the oily water discharges into the Caspian Sea was continuously violated during Soviet times. In the same report, (NEAP 1998), it is stated that "waste transfer to the shore was not performed at all" or was poorly managed. The reasons for that are expenses and difficulties associated with transportation of this waste by sea and possibilities of spills, especially in stormy weathers, which are usual for Baku Bay. These wastes for a long period of time have been discharged into the Sea and in accordance with NEAP (1998) by that period still were being discharged in violation of the existing regulations. This law is still in power. Currently, SOCAR and MENR have to find the solutions for the improving of environmental situation in the region as a whole and Caspian Sea ecosystem particularly.

The system of EIA implemented in Azerbaijan in 90s at the moment cannot be called the effective tool for implementing the environmental policy; it still requires the development and modifications (Bektashli and Cherp 2002). The process of EIA and all its stages are better understood by foreign companies, rather than local enterprises. In this respect the development of understanding among citizens is the step which further should be implemented to achieve the system of effective EIA process.

It worth mentioning that the general absence of environmental awareness among populations makes it difficult to implement and enforce the environmental concepts into the legislative system. The general tendency is the absence of understanding of the environmental element of the law among public.

Furthermore, Azerbaijan has ratified a lot of international conventions, which became the law of the republic. That can be seen as a positive feature in the implementation of main environmental legislation. On the other hand, few actions were implemented in country in regards to these conventions. For example, Ramsar convention signed by Azerbaijan, has designated potential sites for special protection, but the site studies have not been conducted in Azerbaijan in this regards and still no actions have been implemented (Shelton 2003).

Environmental standards for the Caspian Sea are one of the crucial issues for the control of the ecological situation on this waterbody. (Effendiyeva 2000). The standards used by the foreign companies previously involved in operations in the North Sea, Gulf of Mexico cannot be applied to the Caspian Sea case. The Caspian Sea is significantly different due to its closed nature and hydrochemical characteristics. By Effendiyeva, (2000) there is a great difference between international standards and former Soviet Union standards, which are still used in Azerbaijan. The former Soviet Union standards were developed by scientific researchers and in most cases are far from the reality.

The foreign companies working under the PSAs have special legal obligations under this agreement. These companies use different local and international standards in their practices, (for example IFC and WB standards). If some of the standards do not correspond to each other, especially in specified discharge parameters, the most stringent one is selected for implementation. One of the PSA objective states that the foreign companies involved in oil and gas production in Azerbaijan should meet international standards. This statement is tricky, as the term itself is not defined and can also mean and be synonymous to the BAT. BAT itself is not a standard but can be an alternative and useful tool for the decision making on the proper treatment technology, but in some cases BAT can be not appropriate for particular case and exceed the required standards, what ultimately will be associated with the unnecessary costs. In this respect the necessity of the national standards should be recognized.

The oil industry wastewater in the republic is regulated by series of the so-called USSR Branch or State Standards. Most of them created during Soviet times represent a series of regulations on the environmental protection of hydrosphere and the wastewater purification processes. They contain instructions on undertaking the evaluation of environmental risks related to the offshore development and exploitation. The main idea of the standards is clear but in light of current realities, there is a necessity to conduct a considerable review and modification of the existing standards. This review will probably require monitoring activities to verify the current state of the oil wastewater management and provide legislative base to regulate the existing practices. This process is not an easy one, as in addition to monitoring the review of the existing technologies will be required, as all the technologies mentioned in the standards are outdated and not correspond to the nowadays realities.

7.5 Potential Future Solutions for Wastewater Treatment in Azerbaijan Oil Industry

Produced water is a huge wastewater stream. But it should not be considered as useless component. Produced water if managed properly can be useful. It can be first of all, used for the re-injection into the well purposes. The produced water stimulates the well enhancement of oil recovery wells if re-injected. Also, there are a lot of constituents in the produced water that can be used in some technological processes. If the required treatment technologies are used some useful constituents can be extracted from it and used. Moreover, there are options to use produced water for irrigation purposes. There are some successful examples when produced water irrigation projects have been implemented (e.g. in Kuwait), (Hubail and El-Dash 2005). Produced water as well, can be used for the wetlands management projects, for dust regulation purposes and so on. Cleaner Production concepts are implemented in many industries to develop less environmental damaging production processes and more efficient use of resources. Oil and Gas industry is not an exception and there are different studies available on the cleaner production concepts applied to the produced water treatment and management (Campos at el. 2008).

BP has chosen the pipelines construction for produced water to transport it after treatment to the offshore platform for re-injection to support well pressure. The company, after the estimations of the potential produced water volumes has realized that the disposal routes available now will not be sufficient for the disposal of this coming volumes of produced water. Expecting the peak of produced water generation, the decision was taken to construct the pipeline, which will take the treated water from onshore Sangachal Terminal to the offshore platform for re-injection. This project is not the cheapest one but that was the most feasible decision after the review of all the available technological solutions. In addition to the construction of the pipelines, there are a lot of other “onshore” tasks to be solved for the project implementation.

The quality of the produced water after treatment for re-injection should correspond to the standards required for re-injection into the wells, especially TSS and Oil in Water levels. Otherwise the poor quality of treated water can cause the well plugging. The general practice is that the levels of TSS and oil in water content in the treated water for re-injection should be 10 mg/l and 42 mg/l respectively (Bader 2006). The numerous examples demonstrate that it is not easy to achieve these levels. Another criteria for the water quality is pH. As it was discussed in the Chapter 4.3.1 Composition and Structure of Natural water, the pH level demonstrates balance between acids and gases. In the produced water some gases such as CO_2 and H_2S will be lost from the water components and it will lead to the change of the pH level of produced water. This will cause the change in the chemical and physical characteristics of the produced water. Such changes should be considered while re-injection of the produced water into the well. Therefore, the treatment solutions should be sought to improve the current system of treatment units. It will require further research and trials.

Another, potential problem with the re-injection is that the water from one well is not sufficient for the re-injection into the same well for pressure support. In this case, the produced water from different production wells is gathered and injected into the well. In case of BP, the produced water form all offshore production platforms will be collected at the terminal and then treated for re-injection. The characteristics of the produced water from different reservoirs can alter. And it can potentially cause problems with its treatment as in the process of mixing the level of TSS can increase. For example, as it was found out in the interviews with BP Engineers, the chemical composition of Central Azeri and Chirag platforms is different.

Another important issue with the quality of re-injected water is the oil content in it. There can be three different types of oil content in produced water: free oil, dispersed oil and dissolved oil. Depending on the type of oil content in the produced water the content of hydrocarbon species is different. Therefore, in selecting the technology for produced water treatment to remove oil content in it, it should be considered that the amount of oil in water from different reservoirs does not determine the content of hydrocarbon species in them.

Taking into account the difference in the characteristics of produced water from different wells, it can be suggested that it is ideal to treat these waters separately. But in most cases due to reasonable technological and practical issues it is not possible.

The most logical recommendation in this respect would be to take a proactive approach and study all the characteristics of produced waters from different fields to find out their compatibility and decide on the treatment methods to be used to achieve the required quality of water for re-injection.

The artificial wetland is another potential option, which can be considered as a future solution for the treatment of produced water. The ecologists around the world were actively participating in the discussions concerning the using of produced water for the purposes of its bioremediation. The successful projects implemented in different countries demonstrate that if performed properly, this option can be considered as one of the most sustainable way to discharge the treated produced water (Je *et al.* 2006; Benko and Drewes 2008). For this option the mains risk is the discharge of oily water not treat properly into the wetlands, that may cause negative impact on the ecosystem, birds and wildlife. This risk can be mitigated by using proper equipment for the removal of oil content and other chemicals from the water. On the Apsheron peninsula there is a territory located below sea level, where salt marshes are located. These marshes provide habitat to unique species in the region. Due to the salty nature of the produced water, after the treatment methods applied it can be possible to create the salt marshes near with the production site and the sea using reed bed technology described in Chapter 4.6.3 – Constructed Wetlands. The treatment system should be capable to remove heavy metals, hydrocarbons and other chemicals. This technology can represent the problem for the implementation related to the land it occupies. In addition the research will be required on the treatment before discharges and the ability to remove the constituents of the specific produced waters.

The usage of produced water for irrigation purposes is also an actual issue, which was studied by different countries. The water demand around the world is high and water related problems are usual in many countries. In Azerbaijan the main demand for water is for irrigation purposes. The volumes of treated produced water can be efficiently used for these purposes. China and US experience in that area could be taken into consideration. The main aspects which should be considered is the salinity and oil and dissolves organic removal, and softening of water hardness. The technologies, which are currently available or potentially available in Azerbaijan and overviewed in previous chapter, can remove constituents to make the water suitable for irrigation. To reduce the salinity level after treatment the mixture with other fresh waters may be required.

In this respect the environmental and social issues should also be considered. Different crops can tolerate the different level of salinity. In Azerbaijan the standard exists, which discusses the quality of treated wastewater to be used as irrigation water (Environmental Law GOST-33-2.2.02.86). But if the indicated parameters from this standard are compared with those used in other countries, it can be seen that the standard is simplified and maybe cannot guarantee the absence of negative impact on the environment. A project of this kind has never been implemented in Azerbaijan before and there are no comprehensive studies for it on the governmental level, though one study was conducted in this respect for BP in 2002. Furthermore, the implementation of this option probably will require a lot of effort for overcoming the perceived ideas about the re-use of produced water for crops watering.

Overall, this option is very attractive, especially in the global water related problems perspectives. It provides opportunity to use water resources in efficient manner addressing the current challenges with water supply. Therefore, the recommendation could be given here to conduct further studies on the quality of water that can be achieved by using the available technologies, then to investigate the specific characteristics of soil and crop types, and finally to study the social aspects related to this technology.

Summarising this paragraph it should be emphasised that nowadays there are a lot of technologies existing internationally and locally. Their implication to the Azerbaijan produced water scenarios is possible. The main focus should be made on the potential re-use of this water stream. Unfortunately, many studies on the potential water re-use in Azerbaijan are in their infant state and further research is required. Azerbaijan always was experiencing the problem with water and the potential for its re-use should not be ignored in light of global and local concerns about water supply.

7.6 Integrated Approach and Available Options for Produced Water Management in Azerbaijan Oil Industry

Water is a finite resource. With the population growth, the demand for water increases. Therefore, people around the world face challenges related to water supply. Water re-cycle, re-use practices in some extent can help in addressing these challenges. Water re-use practices included into the water policies can provide considerable benefits and create long term sustainability for water resources. There are a lot of studies conducted and projects implemented in many countries of the World on water re-use. The following aspects related to the water re-use projects, should be considered while project implementation: environmental, safety, social, technological, economic and scientific, which are the key factors, influencing the successful implementation of the integrated water projects. Wastewater produced by Oil industry represents a huge source for re-use and re-cycle. To ensure its rational use the aforementioned aspects should be carefully considered.

The environmental and safety aspects are mainly related to the concerns about the quality of the purified water and its possible negative impacts on the environment and people's health.

Social aspects are related to the public reaction on the re-used wastewater. In Azerbaijan these projects have not been implemented yet and social reaction will be very important issue and challenge, which should overcome. In this respect the authorities and people can resist to the options with oily wastewater treatment and re-use, especially using wetlands and as irrigation water.

The new technologies exist for the treatment of oily wastewater in Azerbaijan but the match of these technologies with the intended usage of wastewater should be further researched. Some practices suggest the combination of treatment technologies to achieve the specific water quality but all these studies and researches have to be systemized applicable to Azerbaijan oil industry wastewater.

As it was mentioned earlier, oil industry generates different wastewater streams. The integrated approach to the wastewater management could be a possible solution to overcome a lot of problems related to the wastewater treatment and discharge. Oil wastewater re-use options are sustainable alternative for water management. It can reduce the amounts of treated wastewater discharges into the environment and impacts on water ecosystems related to it.

Going back to the case studies, it can be assumed that there are a lot of options for the implementation of integrated approaches to wastewater management. As it was discussed in the case study analysis BP uses different approaches to oil and gas produced water management due to commercial agreement. It is also recognized that volumes and characteristics for the gas and oil reservoir produced water are different. Therefore, the technologies applied to their treatment vary. But the possibilities to integrate the re-use options for these two water streams exist.

Oil and gas produced water are now stored and treated separately. Gas field wastewater will be not used for the long-term offshore re-injection project but instead will be re-used after treatment in the cement production. If the chosen technologies provide opportunities for the treatment of produced water from oil and gas fields it further can be used together for irrigation purposes or for the artificial wetlands projects. The treatment mechanism may be different but final disposal route can be the same. This can require further research on the compatibility of these streams and depending on that the appropriate strategies can be developed.

Another possibility for the integrated approach is the consideration of produced and open drain wastewater streams. After the removal of the impurities in the open drain waters it also can be used in the process of water re-use together with produced water.

Another option is to use treated open drain water (which is mostly rain water with some oil content or chemicals) for the mixing with the treated produced water to reduce its salinity, if the irrigation option is considered. For the same purposes the treated sewage can be considered.

For the wetlands treatment option the combined streams of produced water and sewage water can be considered. These wastewater streams will require different treatment applied before discharge to reed beds ecosystem. For example, produced water should be treated through primary, secondary and filtration stages, while the sewage wastewater can pass only primary treatment before the discharge. At some point it can be technologically possible to combine the streams and discharge to the wetlands treated produced water and sewage water. This could be a good opportunity to have one treatment unit for all the wastewater streams. The benefits of integrated approach to wastewater treatment can have the following benefits:

- the construction of different treatment units can be avoided
- less energy will be used if wastewater streams are combined in one treatment system

- less labor required for the control of the units and monitoring activities

Overall, the management options for produced water in Azerbaijan oil industry can be considered from the “three stage” waste management hierarchy standpoint – minimization, recycle and re-use and disposal. (Veil 2007).

From the minimization point the option for reducing the volumes of produced water generated can result in more environmentally sustainable approaches to oil production. Technologies exist which can minimize the volumes of produced water reaching the surface. Usage of polymer gels and dual-completion pumping system can reduce water content in oil and produce more or less oil-free water. This can reduce costs related to the produced water treatment onshore. For Azerbaijan Oil Industry the review of the existing worldwide technologies for the wastewater minimization should be considered as it can provide good opportunity for the cost savings and more environmentally sound management of produced water.

As described above recycle and re-use of produced water is another alternative to the sustainable development of oil industry. In most cases, produced water is re-injected into the wells for the enhanced well recovery. The re-use of produced water for irrigation or wetlands construction purposes after the proper treatment is challenging, not an easy task but possible task. Produced water contains high concentration of salt and putting this water into new re-use options requires special technological efforts.

In cases when the produced water cannot be managed through minimization and re-use/recycle alternatives, its disposal is considered. The treatment of produce water in this case is required, where the main aspects are the removal of oil and grease and salt content. In this case, such technologies as Ion exchange, hydrocyclones, membranes and many others have to be considered.

It is realized that all the proposed integrated approaches will require additional research and studies on the technologies available and possibilities to combine the wastewater streams. Ultimately, the integrated wastewater management approach can be a crucial element of the sustainable development of the industry itself.

Chapter 8: Recommendations

Taking into the consideration the main aims and objectives of the research the following Chapter is discussing the recommendations, which are based on the findings of the current research. For the convenience the recommendations are addressing SOCAR and BP findings separately. In addition, the division between short term, medium term and long term recommendations is provided.

8.1 BP Recommendations

8.1.1 Short Term

- As it was found out during the research currently there are cases when the water after passing through the treatment still did not correspond the required standards for further re-use in the well re-injection. In this regards as the short-term recommendation it could be suggested for BP to identify the reasons of equipment failures and eliminate it. The proper performance of the treatment units can help to avoid keeping produced water in the evaporation ponds thus odor issue and other environmental related issues will be eliminated.
- The disposal routes available now can be extended. In this regard, it can be recommended to investigate the other available option for the disposal of produced water after the proper treatment.
- Open drain waters, which get less attention at the moment due to its volumes and impacts on the environment that are less considerable than those of produced water. It also should get proper consideration. In this respect, it is recommended to identify the main risks related to the open drain water and install new equipment for the proper treatment of the contaminated open drain water.
- The current system of the wastewater management is performing without any considerable failures and concerns, but there are some gaps existing in it. From that point of view it is recommended to identify the gaps in the management system and develop improvement steps related to it.

8.1.2 Medium Term

- As it was found out in the research the company is now involved into the construction of pipeline to implement its long-term plans for produced water management. In this respect it is recommended to the company in the medium-term perspective to use proactive approach and initially identify the quality of produced water from all the offshore platforms and decide on their compatibility and potential future problems that it may cause.

- Oil and Gas related produced water is treated and managed separately at the moment, due to the specific nature of this wastewater stream and the current contractual responsibilities. It could be recommended in this perspective, to investigate the possibilities for the integrated approach to the management and treatment of these wastewater streams. In these regards, the measures required for the implementation of this integrated approach should be identified and reviewed.
- Due to the fact that the produced water volumes are predicted to increase for the coming couple of years, the recommendation to the company is to identify and decide on the technology and treatment units that should be used to provide the proper treatment of the increased water volumes.
- The holistic approach to the wastewater treatment is another issue that should be investigated. The possibilities of the integrated approach to the further re-use of sewage water, produced water and open drain water should be identified and properly studied.

8.1.3 Long Term

- In the long-term perspective it is recommended to the company to consider possibilities for the future re-use of the produced water in the wetlands and for irrigation purposes. It is more sustainable use of the wastewater, the possibility of which should be properly studied. In light that a study has already been made for BP on the produced water use for irrigation purposes, it is recommended to concentrate more on the social and technological aspects of this project. In this respect, it also can be recommended to develop the awareness raising among the authorities and local population on the produced water re-use perspectives to overcome the existing stereotypes existing in this respect. From the technological point of view, the existing study does not provide the detailed information on the technology available in Azerbaijan and their applicability to the treatment of the existing and predicted volumes of produced water. Most of the technologies listed in this study are considered to be “potentially available technologies”. It is recommended thus to identify the technologies and the requirements for their implementation to this particular case.
- It is also recommended to the company to develop analytical methods for the produced water laboratory analysis. Currently the independent laboratory is conducting the analysis

for the company using their methodology and analytical methods. Sometimes the parameters, which are analyzed are not required for the produced water quality standards identification in accordance with the existing standards for that. In this respect it is reasonable for the company to decide on the required parameters to be analyzed and analytical methods, so that it is properly communicated to the laboratory for future monitoring perspectives.

8.2 SOCAR Recommendations

Most of the SOCAR recommendations are short-term, as the issues that are addressed by these recommendations require urgent consideration, discussion and study.

8.2.1 Short Term

- As it was identified in the research SOCAR needs to implement some considerable efforts for the establishment of the proper waste management strategy and system. In this respect the first and the most important recommendation is the establishment of proper system of wastewater management with the specified monitoring activities and responsible people. The combined monitoring activities with the MENR can be recommended. Produced water should receive special attention in this strategy as most of SOCAR wells are old and it can be estimated that the volume of produced water is high with its exponential increase potential.
- Based on the current research it can be implied that most of the contaminated lands were inherited by SOCAR from Soviet times. In this respect SOCAR has to identify the past and current contamination sources. For the old times contamination the level of pollution should be identified and all the existing contaminated sites are registered. For the current contamination the reason for it should be identified, whether it is mismanagement or outdated technology problem. Once identified the measures should be implemented to overcome the existing problems.
- Another recommendation related to the previous one is about the implementation of the proactive approach to the wastewater treatment and identification of the wells that will potentially produce most produced water. The studies on the available wells and their current and potential produced water volumes should be part of the wastewater management strategy.

- Open drain water representing another wastewater stream and not mentioned in any SOCAR documents also should be part of wastewater management strategy and mitigation measure should be developed to avoid contamination of land with this wastewater stream. Generally, all the wastewater streams should be considered in the strategy.
- Currently there are not any comprehensive studies on the produced water contaminated SOCAR operational sites. It is recommended to conduct serious monitoring and identify all the scale of the problem so that the proper mitigation measures can be applied.
- As it was found out in the course of research the equipment used by SOCAR is old and primitive. In this respect it can be recommended to the company to identify the gaps existing in the performance of currently used equipment and decide on the appropriate measure related to the update of the existing equipment.

8.2.2 Medium Term

- From the medium-term perspective it is recommended to SOCAR to conduct feasibility study on the main produced water related problems and ways to mitigate them. Currently only scattered information is available and no detailed studies and investigations have been conducted.
- Currently it is not very easy to get wastewater-related information from SOCAR. It is recommended to the company to develop the proper level of transparency related to the environmental issues in general and wastewater in particular. In this respect, the company is recommended to issue the special guidelines describing the environment related problems and the measures implemented by the company to overcome them.
- The recommendation for the study on the existing equipment was mentioned in the short-term recommendation part. In the medium-term perspective it is recommended to the company to conduct the study on the existing BAT available on Azerbaijan market and its applicability to the SOCAR generated produced water.

8.2.3 Long Term

- Based on the research it can be implied that the environmental situation in the region requires considerable improvement. Most of these environmental problems are related to the oil and gas industry development. For SOCAR future plans it can be recommended to take the lead in the overall improvement of the environmental situation in the region as the company is the main representative of oil and gas industry in the country.

- SOCAR is a company controlling all oil and gas operations in the country. From that perspective it is recommended to the company to establish a dialogue between the oil companies operation in the country. It could help to develop networking and the ideas could be exchanged between these companies for the environmental protection measures and overall wastewater management system development.
- As it was found out in the research the existing national legal standards for the oil wastewater is not well developed and most of them are not corresponding to the reality. In this respect, it is recommended to SOCAR to identify the existing gaps between national and international legislation. In this respect the dialogue with the governmental authorities and MENR should be established for the wastewater related laws and regulations update.

8. Conclusion

Produced water is one of the main concerns for oil and gas producers. Around the World, the overall produced water production rates are several times production rates of oil. Due to specific characteristics of the produced water, it is very difficult to treat it. Currently, there is not any single equipment unit that can purify the water to the required discharge or re-use standards. As a result, produced water management should be considered in its complexity, and integrated approach should be implemented to address all the treatment aspects of the produced water. Usually, the complex of treatment measures is used to reach the required water characteristics. Furthermore, with the aging of the well, the volumes of produced water increase exponentially. Therefore, it can be concluded that produced water is not a simple wastewater stream.

The current research conducted on the management and treatment of produced water and open drain water in Azerbaijan Oil Industry was focused on the following aspects:

- character and volumes of produced water streams from two leading oil producing companies in Azerbaijan
- existing technologies for the treatment of produced water and their availability on the Azerbaijan market
- potential environmental problems associated with the produced water
- the applicability of the available technologies to the treatment of the Azerbaijan oil industry produced water
- comparison of treatment technologies and management strategies used by BP and SOCAR potential use of produced water

The composition of the produced water and high concentration of different organic and inorganic constituents can represent a threat to the aquatic and terrestrial environment if discharged without proper treatment. The impacts of the produced water discharges can differ depending on the place of discharge. For example, the discharges made to the close aquatic systems, like the Caspian Sea, definitely will have more severe impacts compared with the discharges to the ocean. Most countries recognized this potential threat and in most places discharges are not allowed.

Open drain water is another wastewater stream related to the Oil and Gas Industry, which is generated in less quantities but if not treated properly can as well represent a potential impact on the environment. There is a potential to integrate the open drain and produced water treatment and management systems.

To achieve the required standards and to place necessary focus on the wastewater treatment it is important to evaluate all the positive and negative aspects of different treatment technologies and management approaches. With the expected increase of the worldwide production of water during the oil and gas extraction, the re-use of the water for well re-injection or for other purposes such as wetland construction or irrigation is very attractive for oil producers. Especially in cases when the environmental regulations related to the wastewater disposal become more strict and effective treatment is required to achieve the quality of the water corresponding to the allowed discharge standards.

As a result of the research it can be concluded that there are the following issues for environmental concern related to the produced water:

- re-injection and its impacts on the subsurface water
- discharge to the sea and its impact on the aquatic life
- re-use in the wetlands and as irrigation water.

Based on the research it can be concluded that these environmental impacts can be properly dealt with. Water re-use can be considered as one of the available alternatives and one of the most important tools to achieve sustainable wastewater management in the 21st century.
Provided that the treatment technology and proper management system are chosen, the risks related to the environmental impacts can be minimized to the acceptable levels thus contributing to the sustainable co-existence of oil and gas industry with the environment.

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Personal Communication

Robinson, R. Environmental Team Manager Deputy, BP Sangachal Terminal. Formal Interview. Baku, 10 May 2008

Sumnar, A. Production Engineer. BP Sangachal Terminal. Formal Interview. Baku, 20 May 2008.

APPENDIX 1

Interview Questions

Produced/Oily water related questions:

1. What are the sources of oily/produced water at sites? Please describe the processes in which this type of wastewater is generated.
2. What are the mains challenges existing for the produced water treatment and management?
3. How much of produced/oily water is generated at each process in specific period of time?
4. What is the treatment method used for produced/oily water? What is the equipment used?
5. How are the discharge standards achieved?
6. What are the discharge standards used by the company in respect to produced/oily water?
7. How the monitoring is performed? What is monitored? How frequently? Who is responsible?
8. How effective is the system of the wastewater treatment on the Terminal?

In most cases the technologies used in offshore and onshore installations are considered to be similar, but nevertheless there are some differences and due to that I have decided to subdivide questions further into specific questions related to offshore and onshore fields.

Offshore specific questions:

1. What type of drilling mud is used in the drilling operations? (water based or oil based)
2. Where the mud is discharged? Is it treated prior to discharge? Please describe the process.
3. What are the limits of drilling mud discharge?
4. Are sewage and domestic food from the platforms treated before discharge? Please describe the process and tell what type of treatment is used?
5. How the produced water treated on the platform? What type of equipment is used? (tilted plate interceptor or induced gas flotation or hydrocyclones?) Is it similar to the treatment used onshore?
6. How and by whom the treated produced water is monitored before discharge to the sea?
7. When gas is produced it must be dried from water before sending to shore. What are the processes involved into the? Is glycol (triethylene glycol) used for that separation? What happens with the separated water containing glycol?

Onshore specific questions:

1. What are the onshore operations producing wastewater (except sewage water)?
2. Is wastewater sent onshore for treatment? If yes, from which platforms and what treatment it undergoes before discharge?
3. What is the process of mud drill cuttings treatment? How the mud drilling cutting are transported?