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Corrosion case study on pipeline

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Corrosion, Equity, Diversity, Environment, and Society - Part 1
Assignment 1: Kashagan Pipeline Corrosion

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Big Oil and Big Players

The offshore shallow-water Kashagan oil field in the Caspian Sea, which is located in water depths between 3 m and 4m, is the 11th largest oil reserves in the world [1,2]. The oil extraction complex was built on artificial islands about 80km away from the coast city, Atyrau [3]. It is estimated that the Kashagan reservoir, which is located 4.2 km below the seabed, contains 38 billion barrels of oil, of which up to 14.47 billion barrels are recoverable [4, 5]. Internationally, this offshore oil field was believed to have great potential, becoming Kazakhstan's next major hydrocarbon and crude oil producer [6].

After the collapse of the Soviet Union, little administrative capacity and financial resources were inherited by its constituent states [4]. The independent Kazakhstan government was not able to initiate and operate sophisticated oil and gas projects on its own. The Kazakhstan government had to collaborate with foreign oil and gas companies to develop its oil and gas sector, bringing revenues from its enormous oil reservoirs [4]. The North Caspian Production Sharing Agreements, which were signed in November 1997, paved the pathway for global investments into Kazakhstan's oil and gas industry [4]. The major shareholders of the Kashagan project are big oil and gas companies, as shown in table 1.

Companies	Equity shares (%)
KaziMunai Gas (Kazakhstan state-owned)	16.9
Shell (British)	16.8
Exxon Mobil (United States)	16.8
Eni (Italian)	16.8
TotalEnergies (French)	16.8
CNPC (Chinese)	8.3
Inpex (Japanese)	7.6

Table 1: North Caspian Operating Company Ownership [1]

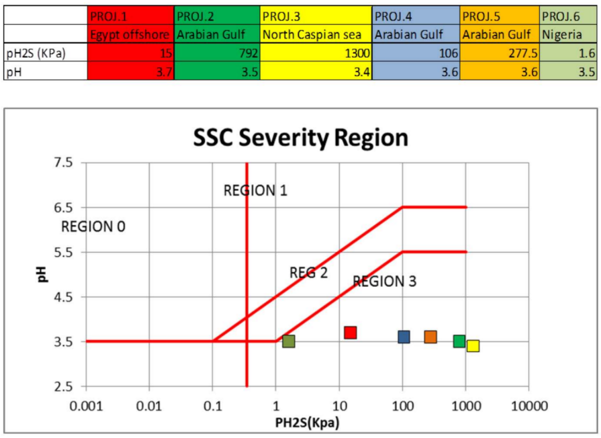
Caspian Hydrocarbon: Transition from Trouble to "Flowing Gold"

The former Soviet oilmen studied the North Caspian Sea and evaluated technical and logistics difficulties associated with corrosion, gas "sweetening", and the harsh winter environment. What is more is that the former Soviet seismologist concluded that the pipeline construction over the Caspian seabed is highly susceptible to submarine earthquakes, which would certainly produce severe environmental, social, and economic consequences to the Caspian region. Thus, the Soviets focused on developing gas and oil projects in Western Siberia rather than in Kazakhstan [4].

After the collapse of the Soviet Union, Russia, Iran, Kazakhstan, Turkmenistan, and Azerbaijan, all wanted to profit from the natural resources in the Caspian Sea, linking their nations' prosperity with the Caspian Sea oil revenue. However, they could not agree on how to split the border and the resources in the Caspian Sea [7, 8]. In 2018, these five countries agreed on how to split the oil and gas resources in the Caspian Sea [7, 8]. More accurately, the 2018 agreement only specifies how to divide the seabed, which contains a lot of natural resources [7, 8]. Prior to 2018, regarding natural resource extraction in the Caspian Sea, Azerbaijan, Iran, and Turkmenistan deployed warships to scare off the contractors hired by the other sides [7]. Russia, Kazakhstan, and Azerbaijan divided the northern Caspian using median lines [7]. The Kashagan oil field off Kazakhstan's coast is an outstanding project that was launched and pressed on successfully in early 2000 [7].

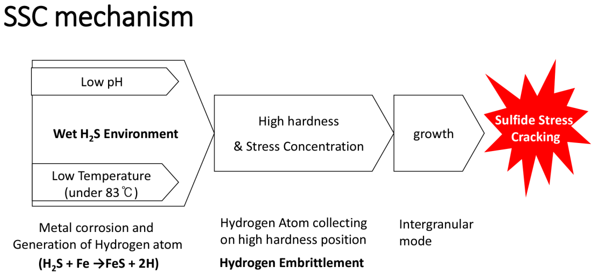
Here is the Problem: Pipeline Leaking Regularly

The offshore Kashagan oil project has been facing challenging adversities since its discovery in 2000 [9]. The full-scale production has been continuously postponed due to pipeline leak repairs and replacement. The Kashagan field was expected to carry out commercial production in 2013, and the initial production is estimated to be around 26,000 barrels per day (bpd) [10]. After many years of project postponement, the oil production started on September 11, 2013. The production ran into trouble immediately. In September 2013, a gas leak was detected at the onshore gas processing plant. The project was halted, and the residual gas was flared at the field's onshore and offshore facilities [11]. The production was resumed on October 6 and stopped immediately again after a functional failure at Island D facilities. On October 14 and October 16, gas leaks were discovered in other parts of the pipeline [11]. Before the complete oil production shut down, around 320,000 barrels of oil were produced. However, around 2.8 million cubic meters of gas had to be flared after the shutdown. It is suspected that more gas has to be flared because the air monitoring equipment was closed after the second gas leak in October 2013 [11]. The reason for closing the air monitor remained a mystery. In September 2016, the Kashgan oil field re-opened after the completion of the pipeline rehabilitation project [1, 5]. In mid-2017, the production capacity reached 200,000 barrels per day [5]. In 2019, the oil production peaked at 380,000 barrels per day, but another pipeline leak occurred [5]. The production dropped from 365,000 barrels per day to 294,000 barrels per day. As of August 2019, the plant produced 30 million tonnes of crude oil, 8.44 billion cubic meters of gas, and 1.75 million tonnes of sulfur cumulatively [5]. In 2022, the oil production in the Kashagan oilfield was shut down due to pipeline leaks [12, 13]. This gas leakage incident resulted in a production drop from 167,755 bpd to 27,230 bpd [13]. Due to the 2022 pipeline leak, the oil field was shut down for two months to repair the pipeline leaks [14]. In 2023, sour gas leaks were detected during routine sampling [15]. Two offshore injection wells were shut down [15]. The production decreased from 252,133 tonnes per day to 240,525 tonnes per day [15].



	PROJ.1 Egypt offshore	PROJ.2 Arabian Gulf	PROJ.3 North Caspian sea	PROJ.4 Arabian Gulf	PROJ.5 Arabian Gulf	PROJ.6 Nigeria
pH2S (KPa)	15	792	1300	106	277.5	1.6
pH	3.7	3.5	3.4	3.6	3.6	3.5

(a) North Caspian SSC Severity Region



(b) Sulfide Stress Cracking Mechanism

Figure 1: (a) SSC Severity Map [16] @ 2017, Society of Petroleum Engineers
(b) SSC Mechanism [17]
@ 2019, Proceedings of the 48th Turbomachinery Symposium

Root Causes: Sour Gas and High Hardness at the Weld?

The light crude oil beneath the North Caspian Seabed has abnormally high pressure (800 bar) and contains carbon dioxide, highly concentrated corrosive hydrogen sulfide (up to 15%), and mercaptan [18]. In 2013, Kashagan encountered a series of severe pipeline accidents during the sour gas production [10]. The pipeline leak investigation and its environmental aftermath were unavailable to the public. One of the known information is that the pipeline steel is made of Carbon-Manganese steel, which undergoes a thermomechanically controlled process followed by an accelerated cooling [10]. It is speculated that the longitudinal cracks start in the thin section of the hard spots of the Carbon-Manganese steel and propagate through the pipe wall very rapidly. Sulfide stress cracking was suspected to be the most likely failure mechanism for the pipeline failure [10]. The sulfide stress cracking is a hydrogen embrittlement phenomenon but is followed by wet H_2S corrosion [19].

Four regions of H_2S severity are identified in ISO 15156 as shown in figure 1a [16]. In region 0, where the partial pressure of H_2S is smaller than 0.3 kPa, no special attention is needed for the steel selection. Despite having low SSC risk, the use of highly susceptible steel in region 0 is still considered to be a poor material choice. Regions one, two, and three are all Sulfide Stress Cracking environments. Different SSC-resistant steels are required for each of the high SSC severity regions [20]. The Kashagan SSC level, which is shown in yellow, is located in region 3, indicating the highest SSC risk for Kashagan oil production.

Material with high hardness is susceptible to sulfide stress cracking (SSC) [19,20]. For example, carbon and low alloy steels that have a hardness higher than HRC 22 or 250 HV are prone to sulfide stress cracking [19]. For instance, ISO 15156 specified that most carbon and low alloy steel should have a maximum of 22 HRC [20]. The SSC mechanism is shown in figure 1b [17]. The micro-alloy effect in low-alloyed steel or carbon steel is the culprit to unwanted high hardness, leading to SSC in a sour gas environment [19].

Environmental Concerns

North Caspian Sea, which is the mouth of the Ural and Volga rivers, has diverse and rare plants and wildlife unique to this environment. Unfortunately, 20% of the species are on the edge of extinction due to the pollution from oil extraction, untreated sewage, and other industrial activities [8, 21]. During the Soviet time, all oil and gas exploration and production activities were banned in the North Caspian Sea [4]. Also, historically, Kazakhstan has never developed a mature and profitable oil sector because of the nature of the USSR's centralized energy sector [4]. In 1999, the concept of a national gas and oil company was developed after the revision of the Subsoil and Subsoil Use Law [4]. In 2002, the national oil and gas company, KazMunaiGaz, was created after merging Kazakhoil with the national company Oil and Gas Transportation [4]. Since 2004, KazMunaiGaz has grown and expanded its assets in oil and gas sector continuously and actively [4]. This post-Soviet "oil rush" introduced several environmental concerns in Kazakhstan [4]. During the distillation process for producing liquid petroleum gas, a significant amount of sulfur deposits would spread into the air and water, damaging and polluting the nearby ecosystem [21]. The pollution continues even after the gas production stops because the toxic waste tends to last a very long time [21].

Human Health Concerns

The Kashagan field is built 70 km away from Atyrau, a town that had 155,173 residents in 2007 [22]. The population has doubled to 297,724 in 2020 [22]. Any pipeline accident that releases toxic H_2S would affect the health of the Atyrau residents [21]. The H_2S exposure dose and exposure time determine the severity of human health damage [23]. H_2S can be detected by nose-smelling only at very low concentrations [23]. H_2S gas has a pungent and rotten eggs smell at 0.1 ppm. The scary fact and the real danger about the H_2S gas is that starting at 50 ppm, the sense of smell would be knocked out completely, and exposure to higher than 100 ppm H_2S would result in immediate danger to life and heath [23].

Dose	Safe Exposure time and Consequence
0.1 ppm	Rotten eggs smell
10 ppm	Exposure time is limited to 8 hours
15 ppm	Exposure time is limited to 15 minutes and 4 times per day
50 ppm	Lose sense of smell due to olfactory paralysis
100 ppm	Immediately dangerous to life and health
300 ppm	Irreversible health damage such as pulmonary edema
>1000 ppm	High chance of death, low chance of survival

Table 2: H_2S Exposure Consequence

In Kazakhstan, diseases including blood disease, tuberculosis and others are four times more common in the Caspian area than the rest of the country's average [21]. Oil mix water, is used for drinking water in Kazakhstan, which a main reason for citing intestinal infections in the coastal areas of Kazakhstan [21].

Conclusion

The North Caspian Production Sharing Agreements, which was signed in November 1997, paved the pathway for global investments into Kazakhstan's oil and gas industry [4]. Due to increasing gas and oil demand, sour gas production, which is much more difficult and more costly than sweet gas production, started to have an attractive profit margin. Kazakhstan, which has a relatively weak oil and gas sector but a lot of sour gas reservoirs, has started oil and gas production in the past few decades by collaborating with foreign oil companies [4].

Unfortunately, toxic gas leaking accidents occur rather regularly in the Kashagan field, and no detail is made available to the public. Considering the Caspian is a closed sea, any toxic gas and oil leak would lead to highly detrimental consequences in the North Caspian region. The Kashagan pipeline leaks were likely caused by sulfur stress corrosion cracking, a combined corrosion mechanism developed by the presence of high pressure, the high level of hydrogen sulfide(the main "ingredient" of sour gas), and poor metallurgical choice. Improper welding and poor metallurgical examination were blamed for causing the leaking issue.

Currently, no thorough and comprehensive environmental and health investigation is available to the public. The purpose of the current review is to raise the alarm about the inappropriate corrosion management of Kashagan oil production and its societal and environmental consequences.

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