Complexity and specifics of elimination of emergency spills of light hydrocarbons in offshore fields

E V Bogatyreva and G D Vorsina
Department of development of offshore oil and gas fields, Gubkin Russian state University of oil and gas (NIU)
E-mail: galina-vorsina@mail.ru

Abstract. This paper describes the problem and complexity of elimination of gas condensate spill in non-shelf fields. The problems and specifics of emergency gas condensate spill managing are identified. They demonstrate a need for development of a special spill response strategy. The gas condensate spill simulation was performed using the PISCES II software. A summary table of results is presented, physical and chemical properties of gas condensate were analyzed. Relevant conclusions have been drawn.

1. Introduction
Offshore oil, gas and condensate production has a particularly high priority now [1–5]. Special attention is paid to the freezing seas such as the Barents, Pechora, and Kara Seas, where the freeze-up period can last up to 300 days. Such conditions complicate the production of hydrocarbons and also determine the strengthening measures for the prevention and elimination of emergency spills of hydrocarbons [6–11]. Therefore, it is necessary to apply an integrated approach not only to predict emergency spills but also to determine the forces and means in the event of a possible emergency, taking into account the specifics of the considered water areas in which the work is planned.

The existing methods of eliminating hydrocarbon spills deal only with heavy oils, while emergencies associated with gas condensate (GC) spills remain underdeveloped and unexplored up to now. This is confirmed by an accident that occurred on January 6, 2018 in the East China sea, 260 km from Shanghai [12]. The tanker Sanchi while transporting 136 thousand tons of gas condensate collided with a cargo ship and subsequently sank. The coast guard services of three countries (China, South Korea and Japan) were involved in eliminating the contamination. However, the prompt arrival of powers and means for managing the accident consequences failed to show any effective measures performance. The accident of a tanker with GC has showed that there are no effective technologies for eliminating its consequences in the world [13,14].

The analysis of this situation shows the following:
- No timely measures were made to eliminate the GC spill;
- The tugboat had unreliable hull structure;
- There is no appropriate regulatory framework for responding to GC spills;
- There are no effective technologies for elimination of gas condensate under conditions of freezing.

So, a special tactics should be developed to respond to emergencies related to a gas spill. It can be carried out in a form of Plans for the prevention and elimination of emergency spills of oil and petroleum products (PES Plan), which requires a detailed analysis of many factors, including the following:
Thus the aim of this paper is to analyse the methods of elimination the light hydrocarbon spills.

2. Materials and Methods

Taking into account the relevance of the topic and the above mentioned arguments gas condensate was chosen as the object of research. Since the type and specific nature of the oil product is a crucial factor in developing a spill response strategy it is important to analyze its physical and chemical properties.

Here we consider condensate on the surface, the properties of which vary from that of the formation condensate. It is possible to evaluate its physical and chemical properties only by conducting laboratory tests after taking samples.

One will be able analyze the properties that affect the area of the spill having the rated operational characteristics of GC, namely:
- Density;
- Viscosity;
- Fractional composition;
- Percentage of light fractions;
- Pour point and fire point;
- Vapor pressure.

Each of these parameters plays an important role in the GC spill and governs the chosen equipment and measures taken for the spill elimination [15].

Below as an example we consider gas condensate characteristics taken from the sea of Okhotsk field at $T=26.2 \, ^\circ C$, $P=3.1 \, MPa$, Table 1.

**Table 1. Physical and chemical characteristics of gas condensate of the Kirinsky gas condensate field, the sea of Okhotsk**

| Characteristics, measuring unit | Test results |
|---------------------------------|--------------|
| Density, $kg/m^3$               | 705.1        |
| Vapor pressure, kPa             | 162.3        |
| Pour point                      | $-60 \, ^\circ C$ |
| Fire point                      | $-2 \, ^\circ C$ |
| Component-fraction composition  | % mass       |
| Nitrogen                        | 0.006        |
| Dioxide                         | 0.536        |
| Hydrogen sulfide                | not detected |
| Mercaptans                      | not detected |
| Methane                         | 1.463        |
| Ethane                          | 1.755        |
| Propane                         | 3.847        |
| Isobutane                       | 2.066        |
| N-butane                        | 3.911        |
| Isopentane                      | 3.548        |
| N-Pentane                       | 1.161        |
Therefore, the condensate contains up to 20% of light hydrocarbon gases (methane, ethane, propane and butane). The content of light oil products (gasoline and diesel fractions) in gas condensate ranges from 90 to 100%, while its content in oil is not more than 30-40%.

![Diagram of chemical fractional composition of GC](image)

**Figure 1.** Chemical fractional composition of GC.

The condensate is highly toxic, has a low density and higher flammability comparing to other types of oil. During a spill, the condensate rapidly spreads in water, interacting with aquatic environment forming a very thin film, as evidenced by the results of the spill simulation produced in the PISCES 2 software complex (using the field in the Okhotsk sea as an example).

3. Results and discussion

3.1. Modeling of the G/L spill

The main processes of distribution, physical and chemical transformation of petroleum products have been taken into account when developing the PISCES 2 model. These included transportation in the conditions of blowing wind and strong flows, spilling was caused by the forces of buoyancy and turbulent diffusion. Moreover, the processes of evaporation, dispersion, emulsification were considered. The density and viscosity of the residue on the surface and the film thickness were being changed.

The following initial data were used during spill modeling:
- Location of the spill source;
- Type of oil and petroleum product-gas condensate;
- Volume of petroleum product spilling during well gushing within 3 days, according to the requirements of the Government Decree of 14.11.2014 No. 1189 [16] - 990 tons of gas condensate;
- Wave height was 0.9 m;
- Wind velocity at average conditions was 8 m/s;
- The flow velocity was 0.45 m/s, to the South;
- Water temperature was 7 °C;
- Air temperature was 5.1 °C;
- Water density was 1024 kg/m3;
- Shore description was taken from the electronic navigation maps.

To assess the possible consequences of the GC spilling, 4 distribution scenarios were considered:
- With a southerly wind -scenario "1";
- With a westerly wind -scenario "2";
- With a northerly wind -scenario "3";
- With an easterly wind -scenario "4".

Each scenario for the spill spreading was calculated in two versions.
Scenario A: taking into account the most probable wind speed (8 m/s);
Scenario B: taking into account the most unfavorable storm conditions, in which liquidation operations are impossible due to the high degree of explosiveness and threat to the life of personnel (wind speed over 15 m/s, wave height over 2 m). At higher wind speeds, intensive dispersion of hypothetically spilled light oil products and a decrease in the pollution zone are observed).

Table 2. Scenario 1A-Well runoff P5, flow rate is 0.45 m/s, direction Y, wind speed is 8 m/s, direction Y, wave height is 0.7 m.

| Time  | Spilled, tons | Floating, tons | Evaporated, tons | Dispersed, tons | On the shore, tons | Quantity of the mixture floating, tons | Maximum thickness, mm | Area of the spill, m² | Viscosity, cSt |
|-------|---------------|----------------|------------------|----------------|-------------------|--------------------------------------|------------------------|---------------------|--------------|
| "1:00" | 11.5          | 6.7            | 3.5              | 1.2            | 0                 | 6.7                                  | 5.5                    | 15066               | 19           |
| "4:00" | 52.7          | 7.9            | 26.7             | 18.1           | 0                 | 7.9                                  | 4.2                    | 30360               | 138          |
| "12:00" | 163           | 7.9            | 89.3             | 65.6           | 0                 | 7.9                                  | 4.6                    | 29751               | 213          |
| "24:00" | 328           | 7.9            | 183              | 137            | 0                 | 7.9                                  | 4.5                    | 30211               | 235          |
| "48:00" | 658           | 8              | 371              | 279            | 0                 | 8                                    | 4.3                    | 31005               | 247          |
| "72:00" | 988           | 8              | 559              | 421            | 0                 | 8                                    | 4.2                    | 29978               | 252          |
| "73:00" | 990           | 1.2            | 563              | 426            | 0                 | 1.2                                  | 0.8                    | 15863               | 247          |
| "74:00" | 990           | 0              | 563              | 427            | 0                 | 0                                    | 0                      | 0                   | 0            |

Figure 2. The GC spill evolution in time. Black dots indicate the oil spill trajectory after the occurrence of an emergency (marked in orange).
During the simulation of gas condensate spill scenarios, the maximum boundaries of the area of possible pollution and the boundaries of complete weathering of the gas condensate were determined in case of failure to take effective measures to localize and eliminate the emergency spill. The following conclusions were drawn:

1. The presence of gasoline and especially kerosene fractions in the gas condensate composition can result in formation of a stable film.

2. At wind force of 8 m/s, after the oil product supply to the environment is stopped, the estimated spill propagation time in water column will be not more than 2 hours in case of no elimination measures are taken. At the same time the distance from the spill source to the final point of complete scattering of the spot does not exceed 5 km. NB: The considered time is 72 hours - in accordance with the requirements of the Decree of the Government of the Russian Federation of November 14, 2014 N 1189 "On the organization of prevention and elimination of oil and petroleum products spills on the continental shelf of the Russian Federation, in inland sea waters, in the territorial sea and the adjacent zone of the Russian Federation" [16].

It is important to note that the spill was considered not as a salvo release of oil product into the environment, but as a discrete outflow of fluid at a constant rate. That is, according to [16], after 3 day of the gas condensate well fountain, the mass of the spilled substance on the surface of water was 13.75 t/h (990 t for 72 h), after 2 hours (under average conditions) and 1 hours (under adverse storm conditions), under the influence of hydrometeorological parameters, the gas condensate was completely evaporated and dispersed in the marine environment.

It should be emphasized that unfortunately the mathematical modeling carried out in the PISCES II software doesn’t give enough reliable results. In practice, in case of emergency, no mathematical model confirms the convergence of the simulation results with real conditions.

Marine spill response strategy

When choosing a strategy and method of responding to a gas condensate spill, it is necessary to take into account the properties of the spilled substance. Therefore, oil properties allow the prompt localization of oil spill source and its collection from water using mechanical methods (booms and skimmers). For freshly spilled light hydrocarbons, such as gas condensate, diesel fuel, it is not recommended to use mechanical methods of localization and collection due to high fire and explosion risks. As a result, the spilling source-centered localization strategy is preferable for heavy oils, but that does not work for light oils, such as gas condensate.

4. Conclusions

1. There is no specific information and scientific evidence of the environmental consequences of the gas condensate spill.
2. Legal regulation in the field of elimination of oil and oil products spills does not take into account the specifics of gas condensate spills.
3. Requirements for the presence of forces and means of constant readiness sufficient to localize the maximum estimated volumes of spills are impossible in most cases.

Thus, the absence of these data leads to difficulties in calculating economic risks. The understanding of which is necessary to justify the creation and development of new technologies to eliminate the consequences of gas condensate spill.

5. References
[1] Gautier D L, Bird K J, Charpentier R R, Grantz A, Houseknecht D W, Klett T R, Moore T E, Pitman J K, Schenk C J, Schuenemeyer J H and et al 2009 Assessment of undiscovered oil and gas in the arctic Science (80- ) vol 324 pp 1175–1179 doi: 10.1126/science.1169467
[2] Shukla A and Karki H 2016 Application of robotics in offshore oil and gas industry-A review Part II Rob Auton Syst vol 75 pp 508–524 doi: 10.1016/j.robot.2015.09.013
[3] Speight J G 2014 Handbook of Offshore Oil and Gas Operations ISBN 9780080878195
[4] Larchenko L V, Kolesnikov R A and Mukhametova L (2020) Russian oil and gas industry as a sphere of international interests and economic cooperation E3S Web Conf 2020 vol 161 doi: 10.1051/e3sconf/202016101006

[5] Ulstein N L, Nygreen B, Sagli J R (2007) Tactical planning of offshore petroleum production Eur J Oper Res doi: 10.1016/j.ejor.2005.06.060

[6] Mapelli F, Scoma A, Michoud G, Aulenta F, Boon N, Borin S, Kalogerakis N and Daffonchio D 2017 Biotechnologies for Marine Oil Spill Cleanup: Indissoluble Ties with Microorganisms Trends Biotechnol

[7] Kim Y M, Cheong H K, Kim J H, Kim J H, Ko K and Ha M 2009 Scientific basis of environmental health contingency planning for a coastal oil spill J Prev Med Public Heal doi: 10.3961/jpmph.2009.42.2.73

[8] Dickins D 2011 Behavior of oil spills in ice and implications for arctic spill response In Proceedings of the Society of Petroleum Engineers – Arctic Technology Conference 2011

[9] Faksness L G, Brandvik P J, Daling P S, Singsaas I and Sørstrøm S E 2016 The value of offshore field experiments in oil spill technology development for Norwegian waters Mar Pollut Bull doi:10.1016/j.marpolbul.2016.07.035

[10] Margesin R and Schinner F 2001 Biodegradation and bioremediation of hydrocarbons in extreme environments Appl Microbiol Biotechnol

[11] Otsuka N, Usami N, Ogiwara K, Hayakawa T and Saeki H 2000 Experimental Study of a recovery method of spilled oil trapped under a rubble ice field In Proceedings of the Proceedings of the International Offshore and Polar Engineering Conference

[12] Obayashi Y and Mason J Stricken tanker leaves large oil slick in East China Sea Available at: https://www.reuters.com/article/us-china-shipping-accident/stricken-tanker-leaves-large-oil-slick-in-east-china-sea-idUSKBN1F40GV

[13] Qiao F, Wang G, Yin L, Zeng K, Zhang Y, Zhang M, Xiao B, Jiang S, Chen H and Chen G 2019 Modelling oil trajectories and potentially contaminated areas from the Sanchi oil spill Sci Total Environ doi: 10.1016/j.scitotenv.2019.06.255

[14] Sun S, Lu Y, Liu Y, Wang M and Hu C 2018 Tracking an Oil Tanker Collision and Spilled Oils in the East China Sea Using Multisensor Day and Night Satellite Imagery Geophys Res Lett doi: 10.1002/2018GL077433

[15] Starobinets I S 1974 Geological and geochemical features of gas condensates (Nedra: Leningrad)

[16] On the organization of prevention and elimination of oil and petroleum products spills on the continental shelf of the Russian Federation, in inland sea waters, in the territorial sea and the adjacent zone of the Russian Federation: decree of the Government of the Russian Federation of 14 November 2014 no 1189