Technical aspects of gas pipeline operation

Jan Hupka
Department of Chemical Technology, Chemical Faculty
Gdańsk University of Technology, 80-952 Gdańsk

1. Pipeline inspection

The pipeline's underwater part, with the exception of its section close to the shore, is usually situated at a depth which is inaccessible to divers, therefore it is necessary to use unmanned underwater vehicles that are remotely controlled from a ship [1]. In addition to external inspection, the pipeline is also inspected from the inside by using smart pigs. The pigs are transported by the pumped medium. They are equipped with batteries, recorders and a range-finder [2]. Obviously, pigs have their limitations, if they are too long (multi-segmented pigs can reach 4 m in length), and pipeline diameter changes or pipelines have sharp elbows or several branches. Pigs designed for undersea pipelines are much more expensive than those designed for land solutions as they sometimes have to travel sections of a few hundred kilometres, e.g. from an onshore facility to a service platform. In some solutions, pigs cooperate with vesels being outside. Usually, pipelines in operation are subject to inspection once a year. If there is a suspicion of external damage of the pipeline, operation parameters differ from the designed ones, or there is some other reason, then the special inspection is carried out.

The pressure method for testing the tightness of pipeline or its sections is used only exceptionally during operation. As a rule, this is necessary after repairs and there is a potential risk of the sea environment contamination by the medium used for the inspection [2]. Visual, ultrasonic, magnetic and acoustic emission methods are the most commonly used. Losses of structural material, cracking risk, changes in the pipeline geometry (see Fig. 1), as well as the amount and extent of debris are evaluated during inspections. The latter evaluation is of vital importance when selecting the most effective pipeline cleaning technology.

The internal pipeline inspection allows the inspecting staff to very precisely assess the condition of welds and corrosion progress which may result in potential leaks, in other words - find the pipeline's weaknesses. The inspection methods for undersea pipelines, broken down by construction and operation phase, were discussed by Mazurkiewicz in his short almost twenty-year old monograph [1]. Despite the time elapsed, this study has lost none of its relevance in terms of general rules for conducting inspections.

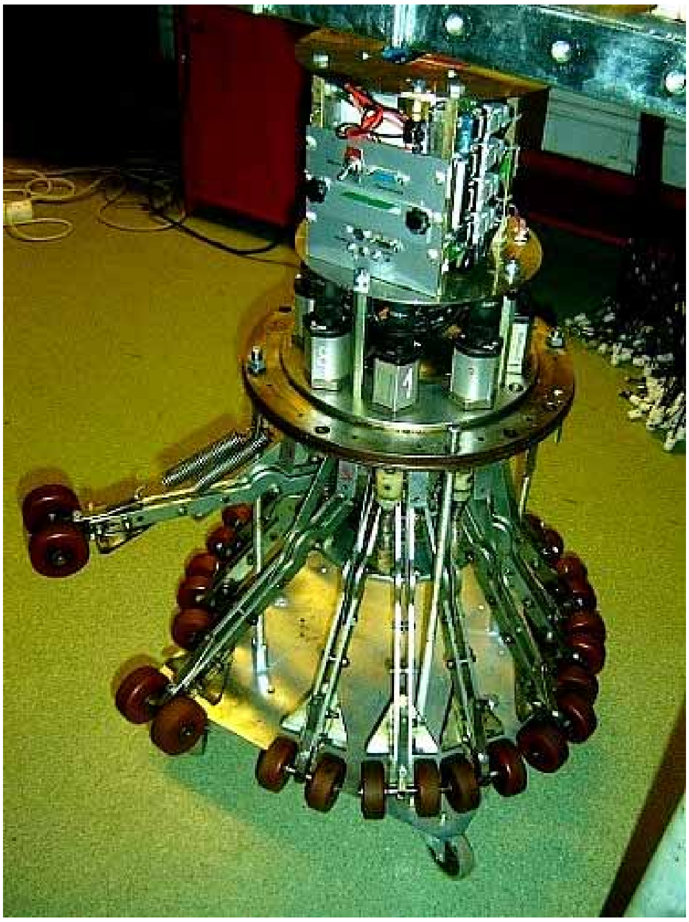

Figure 1. An example of the pig equipped with a pipeline geometry determination system.
(the Pipeline Diagnostic and Equipment Centre PERN in Gdańsk)

2. Formation of hydrates

Methane hydrates (and gaseous methane homologues) forming in pipelines present a serious problem, as they decrease the pipeline diameter resulting in the transmission line's full blockage in extreme cases. The problem is particularly acute in pipelines transporting gas from gas and oil fields. In such a case, it is necessary to add substances, e.g. methanol, that prevent hydrates formation. However, such a procedure has environmental repercussions, as it is not allowed to discharge methanol contaminated water to the sea. The water must be biologically treated.

Gaseous hydrates, being a part of a group of chemical compounds referred to as clathrates, form crystal lattices which contain a gaseous molecule surrounded by a cage of water molecules. Methane hydrate is the most frequent and abundant hydrate to occur naturally [3].

The formation of hydrates is conditioned on a low temperature (e.g. 4°C) and high pressure. Water content exceeding the dew point, high flow rate of gas or strong turbulence facilitate the formation of clathrates. Any blockage of the pipeline causes not only financial losses but also may lead to an explosion and release of large quantities of gas to the environment.

There are some methods preventing clathrates formation, as well as, removing those already formed. The best way of prevention is to entirely remove water from the system. Another method is a chemical one which is based on a thermodynamic inhibitor addition. The commonly used substances are methanol and ethylene glycol. New solutions include adding a dispersing agent (e.g. NH_4Br), which prevents hydrate crystals from forming, or adding a kinetic inhibitor (polymers), which binds to the hydrate surface and delays the growth of hydrate crystals for some time.

In order to prevent the formation of clathrates, the operation pressure should be kept below and the operation temperature above the hydrate formation threshold. Hydrates can also be removed mechanically, e.g. by using previously mentioned pigs.

3. Damages

The major reasons for damages of gas pipelines include [1, 4, 5]:

- internal and external corrosion (about 50% of cases),
- sea operations, such as contact with anchors, fishing nets or ships (about 15%),
- natural threats: storms, hurricanes, earthquakes, underwater landslides (about 10%),
- others whose origin is difficult to determine, e.g. defect in material (about 25%).

As regards the pipelines safety, in particular, given the current political conditions associated with a threat of terrorist attacks, it should be stressed that the pipelines can become the target of such attacks or other acts of vandalism or sabotage [6]. The strategic importance of gas/ oil pipelines in each state's economy makes them vulnerable to military attacks since the destruction of a pipeline transporting gas or oil may strongly disturb the opponent's logistics system.

a. Corrosion damages

While pipeline corrosion damages 20 years ago were chiefly caused by external corrosion (a ratio of internal to external corrosion of 1:3) [1], the most recent data shows quite the reverse [7]. It is due to the fact that the modern pipelines transport gas, which is almost free of corrosion factors, such as water or moisture, carbon dioxide or sulphur dioxide, thereby reducing the rate of internal corrosion.

b. Mechanical damages

The pipeline mechanical damages can be caused by various factors, including material defects, damages to welds, etc. Strict procedures for controlling supplies of construction materials, testing welds and strength tests should reduce such threats. However, such a threat should not be ignored as it is still likely to occur.

c. Damages caused by anchors

There are two possibilities of damaging an undersea pipeline by an anchor. First, when the anchor is dropped directly onto the pipeline [7]. A decision to anchor depends on specific circumstances. Normally, the pipeline is marked on nautical charts, so sailors are provided with information on where they should not anchor to avoid the pipeline damage. However, in case of emergency, such as machinery breakdown or collision, there is a limited number of anchoring options. In such a situation, it is the ship captain's responsibility to make a decision to drop the anchor when the pipeline is likely to be damaged.

The other type of mechanical damage occurs during the anchor drag. It can be caused by a weak anchor catching on the sea bottom or environmental conditions reducing the anchor holding capacity. The distance, which the dropped anchor can travel, depends on the type of sea bed, vessel and anchor weight and vessel speed (Table 1). If the anchor encounters the pipeline, the latter may be bent or even broken.

Table 1. Anchor size and drag distance versus ship class [7]

Class	Anchor (tonnes)	Drag distance (m)
Fishing vessel	1	7
Coasting vessel	2	13
Ocean-going ship	2 – 15	13 – 168
Launch	0.1	25
Fast ferry	0.5	5
Other	0.2	17

4. Gas release consequences

a. Models of spreading of methane in water

According to the Northern Pipeline's designers, if a pipeline bursts under water at a large depth, the gas plume will go through the sea surface by forming a funnel of bubbles (the funnel is about 30 m in diameter) at a flow speed of about 10 m/s (see Fig. 2) [8]. In principle, the way in which methane spreads in water is unknown. Undoubtedly, it depends on the gas release intensity. Some studies show that methane outflow forms a single large bubble or several bubbles (Fig. 3), see chapter 4b.

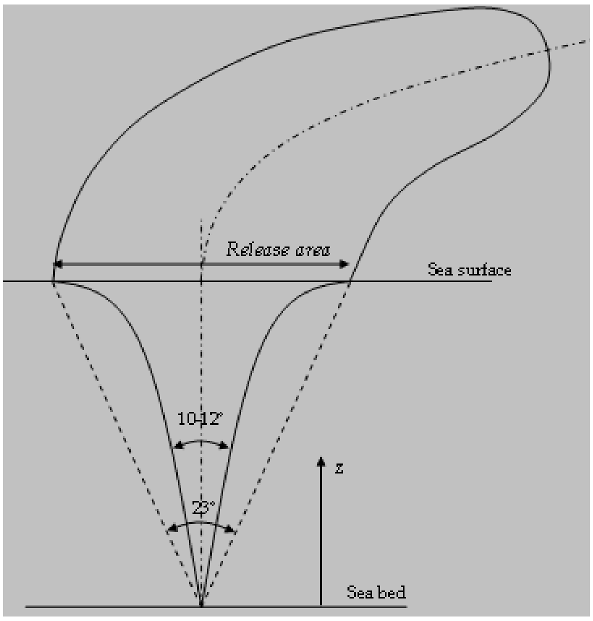

Figure. 2a. Gas spreading: cone model [7]

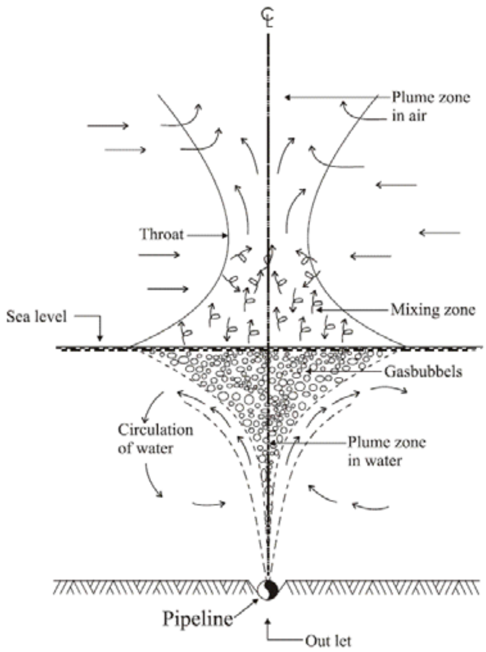

Figure 2b. Water and air circulation diagram for larger gas release [8]

b. Safety of sailing and fishery

If the radius of a large gas bubble is comparable to or greater than the ship's hull, then the ship can sink [9]. Sinking can occur because a mound of water forms above the bubble as it approaches the sea surface. A deep trough forms at either side of the mound and the water flow can carry the ship to one of the troughs (Fig. 3). Whether or not a given ship can sink chiefly depends on its position in relation to the gas bubble. If it is situated far away from the bubble, the ship is in no danger. If it is situated exactly above the bubble, the ship is also safe, because being in a stagnant flow, the ship will not be sucked into the formed trough. The most dangerous position for the ship is between the stagnation point and the edge of the mound where the trough formed. When the ship is not at rest then it is able to move to a safe area by using its own power.

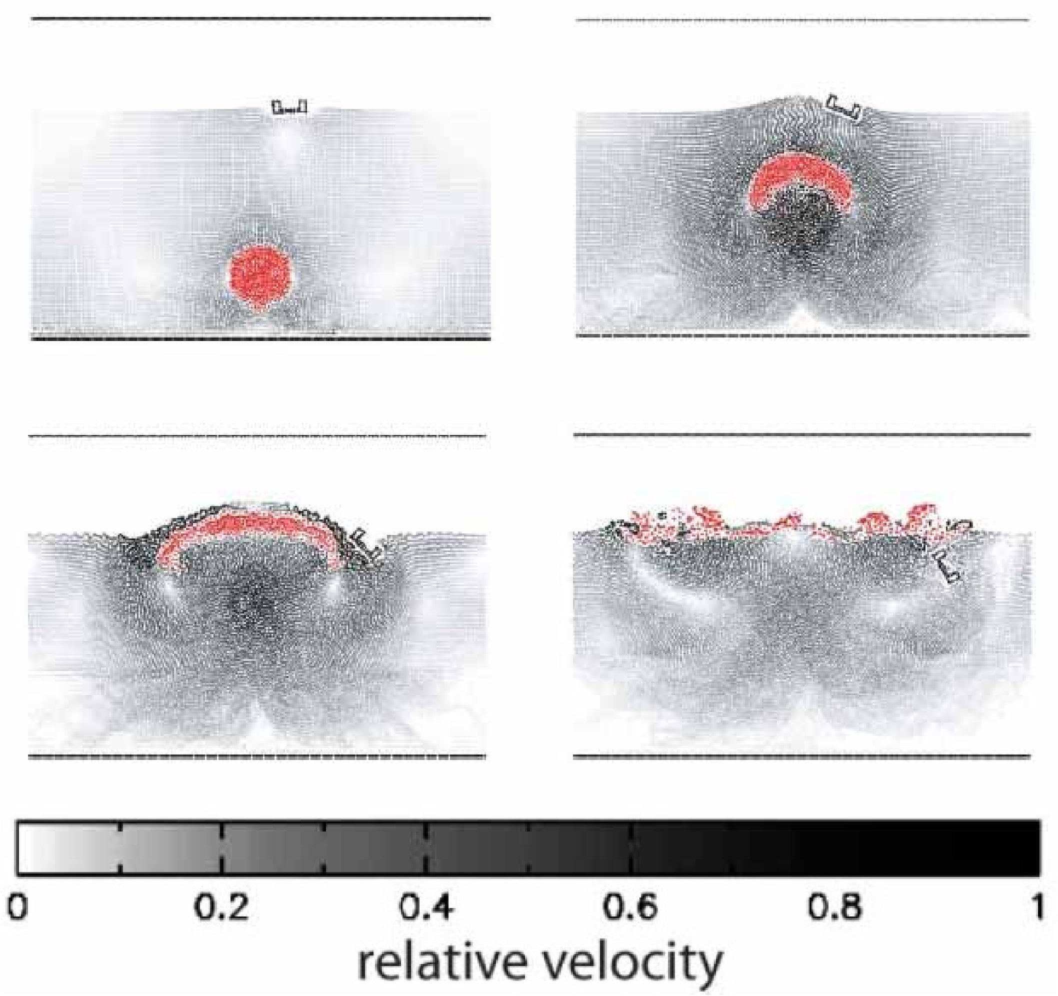

Figure 3. Diagram of the suction of ship by a trough formed by a large bubble [9].

c. Fire hazard

Another consequence of the pipeline leakage is explosion and fire hazard from the methane cloud on the sea surface (Table 2). Explosions and fires can affect vessels and floating platforms and cause financial losses, infrastructure destruction and pose a threat to the life and health of crews and service staff. It should be stressed that the lower explosive limit of methane gas is 5%. This value corresponds to the lowest concentration of flammable substance which maintains combustion process after mixing with air and igniting. Whereas, the upper explosive limit or the highest concentration of flammable substance, at which the mixture contains a sufficient amount of oxidiser required for flame propagation after ignition, is 15%. Under certain circumstances during the pipeline breakdown, although lighter than air (density of 1.29 kg/m^3 at 0ºC, 1.21 kg/m^3 at 20ºC), methane (0.72 kg/m^3 at 0ºC, 0,67 kg/m^3 at 20ºC) can relatively slowly rise and dissipate in the atmosphere thus posing a serious threat to vessels and other facilities working on the sea.

Table 2. Ignition probability calculated for pipeline of 762 mm in external diameter in [7]

Leakage size	**Ignition probability**	
	Flowing vessels (1)	Vessels in the vicinity (2)
< 25 mm	0.01	N.A.
50 mm	0.05	N.A.
100 mm	0.1	0.15
Half bore	0.2	0.3
Full bore	0.3	0.4

(1) Data refers to all types of damages, i.e. caused by corrosion, anchor and other.

(2) Data only refers to damage caused by anchor with the ship being still in the vicinity.

N.A. – not applicable

If methane above the sea surface reaches its local concentration in the appropriate range it will result in an explosion.

A small leakage can result in the formation of methane hydrates on the pipeline and released methane reaching the sea surface where it can feed flames.

d. Methane impact on aqueous organisms

An average methane concentration in the atmosphere is about 1.4 ppm, and its flow in the atmosphere reaches 10^9 tonnes per year. Natural methane concentration in sea water usually varies between 10^{-2} ppm (close to the equilibrium concentration) and 1 ppm. It is higher in coastal waters, gulfs and river-mouths than in open oceans and seas. The vertical distribution of methane in the water column shows a higher concentration in upper water levels and sometimes in lower ones. In the areas of accidental releases of methane its concentration in sea water is even as high as 10^3-10^4 ppm [10].

The knowledge about methane toxicity and its derivatives in water environments is not full. Available information suggests that these hydrocarbons are classified as toxic gases having narcotic and destructive effects on the nervous system. Acute poisoning or even death of a fish occurs at hydrocarbon concentrations exceeding $1.4*10^3$ ppm. Changes in behaviour are observed even at concentrations as low as 30-140 ppm. An important factor is that the fish response to a toxic gas is many times faster as compared with responses to other toxic compounds dissolved or suspended in water.

Acknowledgements

I wish to thank Aleksandra Opara, BSc. and Marcin Janczarek, PhD., from the Chemical Technology Department, the Chemical Faculty, the Gdańsk Technical University, who helped me with the preparation of this study.

Bibliography

[1] Mazurkiewicz B., Inspekcja rurociągów podmorskich, *Studia i Materiały*, zeszyt nr 7, Politechnika Gdańska, 1988.

[2] Improving the Safety of Marine Pipelines, Committee on the Safety of Marine Pipelines, Marine Bard, National Research Council, National Academy Press, Washington, D.C., 1994.

[3] Koh C.A., Westacott R.E., Zhang W., Hirachand K., Creek J.L., Soper A.K., Mechanisms of gas hydrate formation and inhibition, *Fluid Phase Equilibria*, 194-197, 2002, 143-151.

[4] Improving the Safety of Marine Pipelines, The National Academies Press, USA, 1994.

[5] Borysiewicz M., Potempski M., Ryzyko poważnych awarii rurociągów przesyłowych substancji niebezpiecznych. Metody oceny, CIOP-PIB, Warszawa, 2002.

[6] Larson R. L., Nord Stream, Sweden and Baltic Sea Security, FOI - Swedish Defence Research Agency, March 2007.

[7] ERM-Hong Kong, Ltd. Report, Part 2, Section 13, Annex B, 2006.

[8] Offshore Pipeline through the Baltic Sea, Nord Stream AG, 2006.

[9] May D. A., Monaghan J. J., Can a Single Bubble Sink a Ship?, *American Journal of Physics*, Vol. 71, Issue 9, pp. 842-849, September 2003.

[10] Patin S., Environmental impact of the offshore oil and gas industry, Ecomonitor Publishing, East Northport, New York, USA, 1999.

[11] An Introduction to Pipeline Pigging, Pigging Products & Services Association, USA, 1995.

[12] Kissel F., Handbook for Methane Control in Mining, Department of Health and Human Services, National Institute for Occupational Safety and Health, Pittsburgh, USA, 2006.

[13] Karlic S., Zarys górnictwa morskiego, Wydawnictwo Śląsk, 1983.

[14] Pipeline Accident Summary Report, National Transportation Safety Board, Washington, USA, 1996.

[15] Magda W., Rurociągi podmorskie, WNT, Warszawa, 2004.

[16] Brandsæter A., Risk assessment in the offshore industry, *Safety Science*, 40, 2002, 231-269.