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Oil and gas exploration in Europe - innovation and new technologies

Contents

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Foreword

EurGeol. Vítor Correia, EFG President

"In a time of universal deceit - telling the truth is a revolutionary act."
Unknown

Two days ago, on 13th November 2018, the European Parliament adopted eight legislative proposals that introduced new rules on renewables, energy efficiency and the governance of the Energy Union, with the aim of decarbonising the EU economy. I fully support this aim (as I'm sure all EU citizens and geoscientists do). But the push towards a greener economy is understood by the majority of the population as an incentive to use electricity instead of fossil fuels. This perception justifies the boosted demand for solar panels, electric cars or the social opposition to new oil and gas projects in the EU[1]. What no one has explained to citizens– and political leaders should do this – is that meeting the growing demand for electricity in Europe is impossible without including fossil and nuclear fuels in the European energy mix. Making people believe that we can rely only on renewables in the medium term (let's say, by 2030) brings forward a partisan view of the world[2] that pushes young talent away from the oil and gas industry, and the relatively low number of articles in this issue of the European Geologist Journal reflects, in my opinion, the lack of appeal the industry has nowadays.

A reality check shows that, instead of hiding fossil fuels behind the curtain, we should fine-tune and implement a feasible energy mix, capable of meeting the goals of the Paris Agreements and minimising EU dependency on energy imports. Here are some critical facts about oil and gas relevant to this discussion:

- Oil and gas have a high energy density, are a reliable power source and can be easily transported and stocked;
- Oil and gas are the most important energy sources (for electricity production, transport and heating) in the world. Together with coal, they represented more than 70% of the energy production in Europe in 2017[3];
- The European Union is highly dependent on oil and gas imports. More than 60% of the energy consumption in Germany, the biggest economic power in Europe, relies on imports of oil and gas. With the ongoing phase-out of nuclear and coal power plants in Germany, the country's reliance on imports will probably exceed 80% in the short-term;
- Fossil fuels power plants can be equipped with CCS (carbon capture and sequestration) technologies that reduce significantly CO2 emissions, and injecting carbon dioxide into depleted oil wells makes the wells more productive and enhances the overall efficiency of oil production;
- Halting oil and gas exploration and exploitation in Europe will not diminish carbon dioxide emissions in Europe. It just makes the EU more reliant on imports of oil and gas, coming mainly from Russia and Norway.

On top of this, oil is the most traded commodity in the world, and oil geography and prices explain an important part of the dynamics of international politics and conflicts. In this context, EU member state governments should be supporting oil and gas exploration in Europe, because this is critical to meet Europe's energy demand, minimise its import dependency and enhance the security of supply. And the EU is one of the few places in the world where regulations and technology can be used to ensure that oil and gas production can be carried out without compromising the Paris Agreement commitments.

1 Portugal recently banned offshore exploration for oil and gas because of public protests, and the public opposition to resuming shale gas exploitation in the UK is becoming stronger and more emotional.
2 So fashionable in these days of ideological symmetry and fake news, with growing nationalism as a response to liberal trade and global competition.
3 Source: Eurostat, cited in the Energy Union country factsheets (available at ***https://ec.europa.eu/commission/publications/energy-union-factsheets-eu-countries_en***).

It is clear that EU citizens are strongly motivated to reducing CO_2 emissions and fighting climate change. I believe that it's time to explain to them that changes in their behaviour and consumption patterns[4] would have a much bigger impact on curbing CO_2 emissions than banning oil and gas exploration or closing fossil power plants in the EU. Conveying this message to citizens is difficult and can only be done outside the stage of political battles, using statistics, science-based information and clear, easy-to-understand language. Geoscientists can provide the data and the knowledge necessary to underpin the message and support the implementation of sound, effective policies that would strengthen the EU transition towards a greener economy. I am convinced that EU citizens would prefer this approach, which some people might consider revolutionary.

4 On average, Europeans use their car less than 5% of the time and rides only have one passenger (the driver). The Transportation Sustainability Research Center at the University of California Berkeley estimates that ridesharing helps reduce car emissions between 34% and 41% per year per each household using these services (for more information see ***https://tsrc.berkeley.edu/topics/ridesharing***). Hence, the potential impact of using public transportation, ridesharing and carpooling in the reduction of CO_2 emissions from passenger cars is enormous.

Environmental issues of gas exploitation platforms in the North Adriatic offshore Croatia

*Ratko Vasiljević**

Intensive exploration for natural gas offshore Croatia (in the North Adriatic) started in the early 1990s, while oil exploration began in 1998. The annual production of natural gas amounts to approximately one standard billion cubic metres per year, small on a global scale, but during the last twenty years useful experience has been gathered in environmental protection issues related to exploration and exploitation. The North Adriatic is a small semi-closed basin and is sensitive to pollution. Activities of exploration and exploitation, especially drilling activities, were subordinated to environmental protection. Exploitation platforms have been found to contribute to biodiversity and even act as sea turtle protection areas. Production has declined significantly in recent years and it is necessary to plan decommission activities, whose costs could be reduced by leaving some repurposed infrastructure in place. This paper summarizes experiences in environmental protection in North Adriatic during last twenty years, and uses them as a baseline for proposals for the further management of exploitation platforms.

L'exploration intensive du gas naturel, au large de la Croatie (région nord de l'Adriatique), a commencé au début des années 1990, tandis que l'exploration du pétrole n'a débuté qu'en 1998. La production annuelle de gaz naturel atteint approximativement et, de façon ordinaire, un billion de m³, chiffre peu élévé globalement, mais pendant les vingt dernières années, cela a constitué une expérience valorisante et large qui a été acquise pour résoudre les problémes de protection environnementale liées à la fois à l'exploration et à l'exploitation. La région nord Adriatique correspond à un petit bassin à moité fermé qui est très sensible à toute pollution. Les activités d'exploration et d'exploitation, en particulier les activités de forage, dépendaient des conditions de protection environnementale. L'on a découvert que les plate-formes d'exploitation contribuent à la biodiversité et, bien plus, agissent comme aire de protection des tortues de mer. La production a diminué de façon significative ces dernières années et il est nécessaire de programmer des travaux de mise hors service dont les coûts pourraient ête réduits en conservant intentionellement, sur place, quelque infrastructure. Cet article résume l'expérience acquise en matière de protection environnementale de la région nord Adriatique, pendant les deux dernières décennies, et sert de référence pour les propositions concernant une meilleure gestion des plate-formes d'exploitation.

La exploración intensiva de gas natural en el mar de Croacia (en el norte del Mar Adriático) comenzó a principios de la década de 1990, mientras que la exploración de petróleo comenzó en 1998. La producción anual de gas natural es de aproximadamente un billón de metros cúbicos estándar por año, aunque se trata de una producción pequeña a escala mundial, ha permitido adquirir experiencia relevante en temas de protección ambiental relacionados con la exploración y la explotación durante los últimos veinte años. El norte del Adriático es una cuenca pequeña semicerrada que es sensible a la contaminación. Las actividades de exploración y explotación, especialmente las actividades de perforación, respetaban la protección ambiental. Se ha descubierto que las plataformas de explotación contribuyen a la biodiversidad e incluso actúan como zonas de protección para las tortugas marinas. La producción ha disminuido significativamente en los últimos años y es necesario planificar las actividades de clausura, cuyo coste podría reducirse si se emplea la infraestructura existente para otra actividad. Este artículo resume las experiencias en protección medio ambiental en el norte del Adriático durante los últimos veinte años, y las utiliza como referencia para propuestas de gestión posterior de plataformas de explotación.

Introduction

The Adriatic Sea is located between the Italian and Balkan Peninsula. The Adriatic is the north basin of the Mediterranean and enters deep into the Central European mainland. Exploration of the Adriatic offshore region has lasted over 40 years and natural gas exploitation started in 1998.

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The gas in the gas fields is of biogenic nature, occurring in the shallow Plio Quaternary sands and sandstones of the Po Depression mixed with terrestrial organic matter. According to geochemical facies, the gas in the reservoirs of the exploitation fields in North Adriatic is generated by bacterial decomposition, fermentation and reduction of carbon dioxide or acetate, under the influence of methanogenic bacteria during the Quaternary period. In bacterial-derived gas, the dominant component is methane and the content of higher hydrocarbon homologs is less than 1% and belongs to the class of dry gases (Barić, 2006). The formation of bacterial methane occurs in non-marine and marine environments after sulphate reduction has been completed.

Approximately 20 platforms are active; the maximum annual production of gas was achieved between 2007 and 2010 and it reached a total production of about 1.8 billion cubic meters of gas. Another significant production peak, significantly lower than maximum, was in 2012, reaching approximately 1.1 billion cubic meters of gas. Since then, production has continuously decreased. In a do-nothing case, gas field production should last until 2040 (ECOINA, 2013).

Considering continuous depletion in production of hydrocarbons in Croatia, it is necessary to continue with new exploration activities. The Adriatic Sea represents a most interesting target for further oil and gas exploration. Additional reservoirs could well exist in the Northern Adriatic offshore area. Besides the main Quaternary reservoirs with biogenic gas, new targets should be deeper pre-Tertiary carbonates in the northern and southern parts of the Adriatic Sea.

Considering the fact that the Adriatic Sea is a relatively small semi-closed basin, these activities could have a significant environmental influence. This paper summarizes some of key environmental issues recognised in fifteen years of experience in estimation of environmental impact assessment from the exploration and exploitation of gas in the North Adriatic (ECOINA, 2009, 2013).

During impact assessment, some of the most relevant cases were consulted (Patin, 1979, 1998), along with calculation of suspended particles disposed into the sea and spreading of possible oil contaminants. Results were confirmed by monitoring results (PMF/IRB, 2012).

For high-quality resolution of environmental issues, a multidisciplinary approach is necessary, which includes not only geology but also biology, technology, chemistry, process engineering, and other fields.

Environmental issues of gas exploitations

Gas exploitation activities can be roughly divided into three phases: commission and drilling, exploitation and decommission.

Commission and drilling include the position of the drilling rig, drilling using drilling fluids, and accompanying management of used fluid and drilling material. After drilling, the exploitation platform is installed and connected with the connection pipes for other platforms or facilities on land.

In the phase of commission and drilling, the main environmental issues are: noise from drilling that can affect sea organisms, especially mammals; risk of sea pollution from drilling fluids that can affect sea quality and consequently ecosystems; and covering the sea bottom with drilling detritus and placement of pipelines, which can affect benthos (the community of organisms living in, on, or near the seabed).

The second phase is relatively stable, as during the exploitation of gas the only emission into the environment is the discharge of processed formation water into the environment. Due to the prohibition of fishery around platforms and pipelines, the impact on ecosystem is positive since these installations represent shelter for living organisms, especially for endangered sea turtles.

In third phase, decommission, the influence is temporarily and limited to working activities, but given its relatively high costs it may be worth considering the possibility of leaving infrastructure in place to act as artificial reefs.

Calculation of the influence of suspended particles from drilling and exploited formation water discharged into the sea

The main targets for the environmental assessment were particles disposed of into the sea during the drilling process and unprocessed formation water during the process of exploitation. Drilling activities were planned at platforms Ravenna A; Andreina; Ida D; Ika C; Ika SW A and Ika SWB. These activities can have a wide range of influence by spreading through the sea, and some organisms such as benthos are unable to avoid them. Noise can affect sea organisms too, such as fish and mammals, but they are mobile and can avoid these zones during drilling.

Drilling was performed using water based bentonite mud with environment friendly additives. Since the reservoirs contain methane only, polluted by primarily hydrocarbons was not to be expected. Sediments are mostly contributed by the River Po, and this process continues to take place in recent times, so the drilled material is literally the same as that on the sea bottom. For this reason, the solution of direct disposal of drilled material into the sea was chosen.

Formation water is exploited in conjunction with gas, and due to its geochemical properties, dissolved hydrocarbons were not expected. However, before final disposal into the sea formation water was processed gravitationally in a caisson to extract hydrocarbons from lubricant residues from the platform installation stage.

The spread and sedimentation of suspended matter in the sea is primarily dependent on sea currents. Sea currents are created under the influence of winds, differences in pressure, temperature and different salinity. They can be horizontal and vertical. There are currents that appear at the bottom and are caused by moving the water from the warmer into the colder areas, and those that appear when the surface of the sea becomes colder and the cold water convects toward the bottom. The velocity of the current changes from area to area, but also depends on the time period. The average current velocity in the Adriatic is about 0.5 knots (0.26 m/s) but reaches up to 4 knots (2.06 m/s).

Salinity also affects the speed of particle deposition, as it increases buoyancy. The average salinity in the Adriatic is 38.3 g/ml. In the northern part, salinity is lower than in the central and southern parts due to the influence of the River Po. Seawater density is affected by the sea temperature. The average sea temperature is 11 °C. During the winter, the sea is coolest and the surface temperature is about 7 °C. In the spring the surface temperature rises to 18 °C and in the summer to about 22-25 °C, with temperatures up to 27 °C in the northern part.

The North Advent block is influenced by two currents. The southern part of the field is influenced by the inlet of the eastern Adriatic that transports saline water in the Adriatic. This current transfers the water in the northwest direction and changes the direction of the field to the west. The northern part of the field is dominated by the cyclonal currents of the northern Adriatic, which forms the northern Adriatic current, characterised by high density sea water.

During the development of the dynamic model of spreading and sedimentation of suspended particles in seawater for the winter period a 2D numeric model was used. Input parameters for suspended particles are:

- Maximum amount of contributed material from one platform is 180 m^3
- Sea depth ranges between 40 to 70 m
- Disposed material consists of solid particles insoluble in water, non-volatile and not affected by biological or chemical degradation
- Median particle diameter is 200 µm
- Minimum particle diameter is 50 µm
- Average density of particles is 2500 kg/m^3
- The water temperature is 11°C
- Dynamic viscosity m 1.08×10^{-3} Pas
- Kinematic viscosity ν $1.05 \times 10^{-6}\ m^2s^{-1}$
- Salinity (38 g/l)
- Seawater density 1022 kg/m^3

Suspended particles constantly obey Stokes formula and the mechanisms of spreading particles are advection and dis-

Table 1: Characteristics of the caisson for discharge locations (ECOINA, 2013).

Plat-form	Depth of sea (m)	Water column in caisson (m)	Caisson diameter (m)	Outlet surface of the caisson (m²)	Volume of the sub-merged part of cais-son (m³)
Ivana A	41	31.4	0.3	0.071	2.23
Ika A	55	20	0.5	0.196	3.92

Table 2: Flow parameters (ECOINA, 2013).

Platform	Maximum flow of forma-tion water (m³/day)	Retention time in caisson (s)	Flow (m³/s)	Flow velocity at the outlet (m/s)
Ivana A	250	771	0.00289	0.0407
Ika A	200	1 693	0.00231	0.0118

persion only. For calculation of the influence of the formation water disposed into the sea, the chosen density of hydrocarbons was 850 kg/m^3. Average oil density values in standard conditions are between 800 and 900 kg/m^3. All other parameters are the same as for suspended particles.

Concentration of hydrocarbons

Concentrations of hydrocarbons in the formation water, before gravitational processing, were analysed by an ISO 17025 accredited laboratory; values were between 2.04 mg/l (Ivana A) and 8.8 mg/l (Ika A).

Due to large differences in sea density and the density of hydrocarbons (the sea is about 20 % denser than hydrocarbons), immediately after the discharge from the stratum the dominant motion mechanism is in movement towards the surface. After reaching the surface, hydrocarbons move under the influence of surface currents. As the model input, the maximum measured value of 8.8 mg/l of total oils is used, before gravitational separation, in order to simulate the worst-case scenario.

Gravity separation takes place in the caisson at atmospheric pressure so that the level of water in the stratum corresponds to the sea level, according to the law of connected vessels, and for this reason, only the immersed part was taken for the volume (*F*).

For the flow calculation, the maximum values of the level of water to be modelled in the worst possible case were used. Flow parameters are given in ***Table 2***.

Sea currents

For modelling, mean vector velocities of surface currents were taken as:

- Platform Ivana A: 0.08 m/s NW 315°
- Platform Ika A: 0.2 m/s W 270

The concentration limit of 2 mg/l was taken as the limiting condition of the model, which in most cases represents the minimum limit of reliable detection by spectroscopy according to DIN 38409: 1981 H18 used by the authorised laboratory.

For the mathematical model the Bouyant jet model was selected, which is incorporated in the software Disper 2.0. This model is developed for immersed outlets of circular cross-sections and is satisfactory for uniform flow conditions without bottom impact; thus, it is applicable to the location.

Results and discussion

For the given conditions, the following numerical simulation results for dispersion of suspended matter into the sea were obtained:

- The plume of suspended material on each platform is pre-stretched with an approximate length of 4 km and approximate width of 0.5 km (***Figure 1***).
- 50 % of the material precipitates within an area with a length of 200 m and width of 80 m.

According to simulation results, concentrations near the surface above discharge site will be lower than the boundary of reliable detection by the spectroscopy method (DIN 38409: 1981 H 18). Thus, on the surface of the sea near the platform Ivana A (***Figure 2***) and near the platform Ika A (***Figure 3***), detectable concentrations of hydrocarbons in the sea water were not expected.

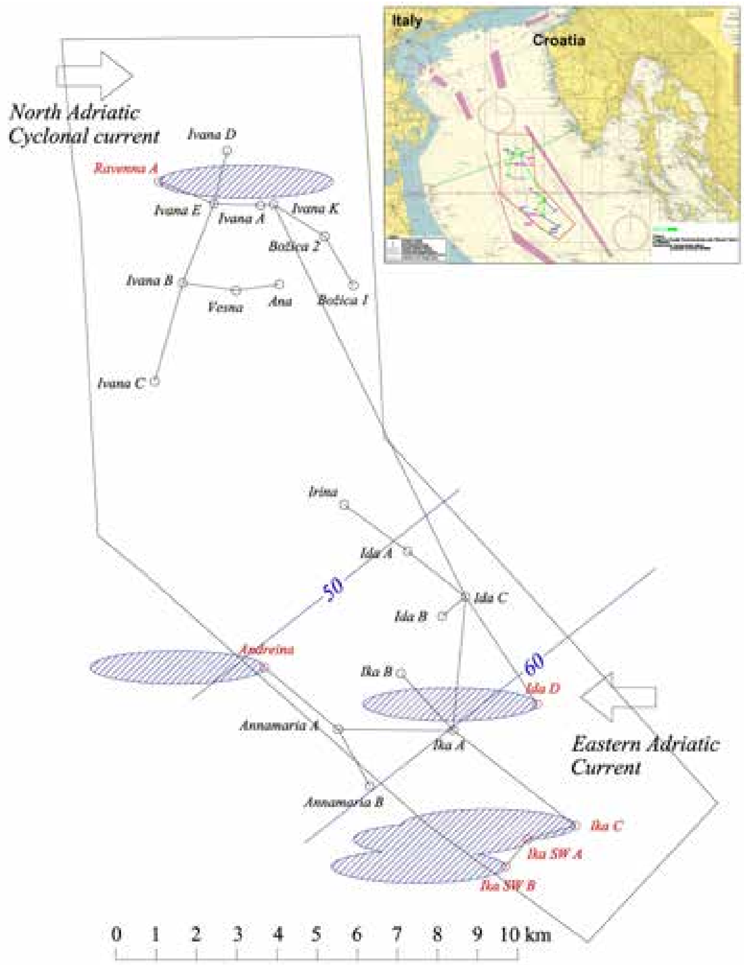

Figure 1: Sketch of the precipitated material from the suspension deposited into the sea from the platforms Ravenna A; Andreina; Ida D; Ika C; Ika SW A and Ika SW B (ECOINA, 2009).

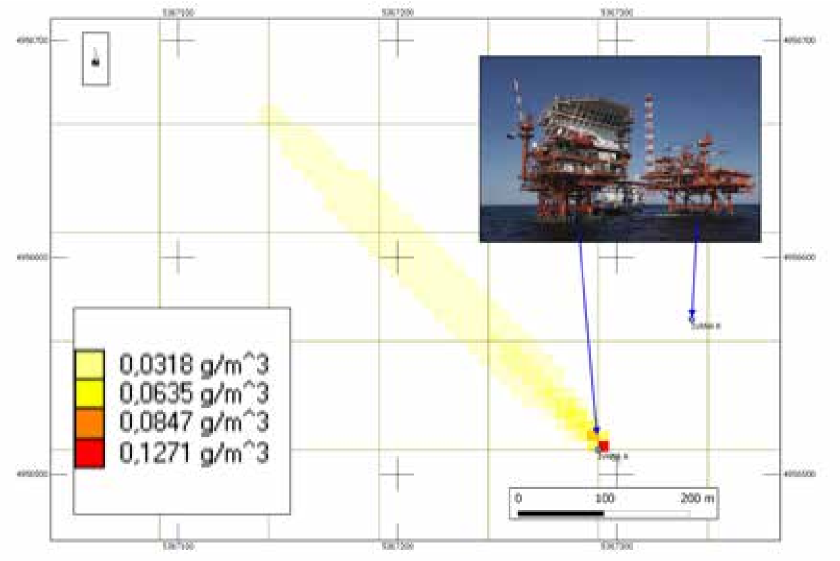

Figure 2: Model of dispersion of hydrocarbons from the unprocessed formation water discharged at Ivana A platform (ECOINA, 2013).

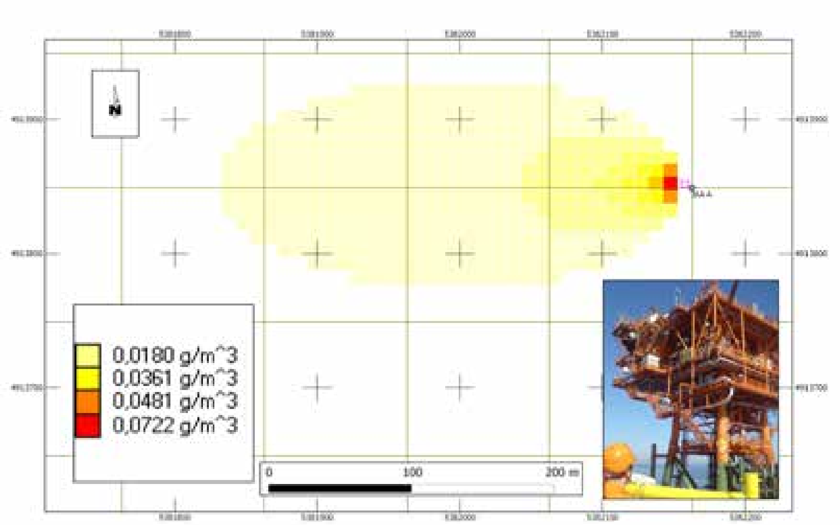

Figure 3. Model of dispersion of hydrocarbons from the unprocessed formation water discharged at Ika A platform (ECOINA, 2013).

The input concentration in the model for all platforms was the maximum measured concentration of total oil on the Ika A platform before entering the caisson. The minimum water retention time in the caisson during the maximum inflow of the formation water is 770 seconds (about 13 minutes) on Ivana A, which is sufficient to extract most of the hydrocarbons gravitationally.

For modelling, a conservative approach was taken; only transport by the sea currents was included in the model, i.e. the influence of the waves – which further affect the dispersion – was not taken into account.

The results of the modelling showed that at a distance of approximately 10 m from the discharge the concentration of pollutant will drop to 0.8–1.5 % of the initial concentration (dilution would be between 60 and 130 times), while at a distance of 300 m concentration will fall to 0.2–0.3 % of the initial concentration (dilution will be greater than 300 times).At a distance of 200 m, elevated total oil content may occur, mostly lower hydrocarbons, in concentrations higher than 50 µg/l. According to research, at dozens of locations in the world, dilution is up to 200 times at a distance of 10 m from the discharge site (Somerville, 1987), a drop in concentration of 0.5% of the initial concentrations of pollutants. At a distance of 100 m, dilution is up to 1000 times (concentration drop to 0.1% of initial concentration of pollutant). At a distance of up to 200 m, the high content of total oils (almost exclusively lower hydrocarbons) may occur briefly in concentrations above 50 µg/l (Somerville *et al.*, 1987).

As the model input, the maximum measured value of 8.8 mg/l of total oils is used before gravitational separation. The limit values for disposal prescribed by the Barcelona Convention are 40 mg/l, so even without the full functionality of the water treatment equipment the oils fully meet the regulatory requirements. Apart from the Barcelona Convention, hydrocarbon concentrations also meet the Marpol convention (although it does not apply to this issue, but only to drainage water from the machinery spaces).

The results of the modelling give a slightly lower dilution than Somerville *et al.* (1987), but as mentioned earlier, the model did not take into account the influence of waves that additionally affect dispersion, i.e. the model represents a conservative estimation.

Mineral oils (PAHs) at concentrations up to 1 mg/l may stimulate or inhibit growth in phytoplankton at higher PAHs concentrations (up to 100 mg/l) (Abbriano *et al.*, 2011). The modelling results have shown that even near the discharge mineral oil concentrations will be below the limit of concentration that could adversely affect phytoplankton. Like phytoplankton, many zooplankton species are susceptible to increased mineral oil concentrations; zooplankton mortality increases with longer exposure to higher concentration of mineral oils (Abbriano *et al.*, 2011). Increased concentrations of mineral oils mainly have a stimulating effect on increasing the number of bacterial plankton. However, due to the low concentration, no increase in abundance is expected, which means no major effect on other members of the microbial feed network.

Potential negative impacts of hydrocarbon exploitation on marine fauna have not been established with the results of research up to now (PMF/IRB, 2012). Namely, based on the results of this long-term monitoring, which covered the review and analysis of the processing of the platform, the toxicity/genotoxicity analysis of the seawater near the platform of Ivana A did not identify an ecotoxicological effect that would represent risk exposure to the organic pollutants, nor did it reveal the presence of pre-mutagenic and/or mutagenic xenobiotics (PMF/IRB, ¬2012).

Issues with decommissioning

A problem that has emerged, not only in the North Adriatic but also in the rest of the world, is the issue of decommissioning.

The International Maritime Organization (IMO) recommends removing the platform when the sea depth does not exceed 100 m and, theoretically, it is quite simple.

1. Cleaning of all armature and gas pipeline from residual gas by inert gas (Nitrogen).
2. Insulation of residual gas and formation water in reservoir by plugging the boreholes. All productive levels in boreholes will be sealed off through cement plugs. The cement plugs shall be preferably set through tubing, using coiled tubing techniques. All casing strings will be cut at the appropriate depth at the bottom of the sea and plugged by cement cap.
3. The pipes from the sea bottom will be cut off the platform and removed.
4. Platforms will be removed by mechanical decomposition (after cutting off all platform equipment) and transported to the land.
5. The construction material of the platforms and pipeline is steel and can be reused as a secondary raw material.

But what about expenses? In spite of the fact that these expenses are calculated, in practice it is never enough. According to information on the website of the Society of Petroleum Engineers, "Global spending on oil and gas decommissioning is expected to be $13 billion per year by 2040." These costs are sure to grow: "In the North Sea, the companies said that in the North Sea alone more than 400 fields are expected to cease production by 2026 at an estimated cost of $56 billion. Globally, more than 700 fields are expected to require decommissioning" (SPE website). These statements are general and each area has its own economy, but it is undeniable that the decommissioning prices are high. In this paper I would like to offer an alternative for solving this problem.

In the North Adriatic area of exploitation fields of hydrocarbons the depth of the sea is between 35 and 70 ms, i.e. according to bathymetry it belongs to the epipelagic zone.

The area of the project belongs to the open sea of the northern Adriatic and the entire water column represents a habitat suitable for tiny blue fish (***Figure 4***). Direct observation also showed the presence of larger pelagic organisms: tuna, dolphins, marine turtles (***Figure 5***).

The research conducted on platform Ivana A (PMF/IRB, 2012) included diving activities by the legs of platforms. According to visual detection, 27 species of fish were recorded in the vicinity of the platform. Some of fish species found shelter and food while others came in search of food, and the platforms were incorporated into the environment as artificial reefs, similar to the natural ones that are common along the Croatian part of the Adriatic coast. Due to the risk of strong currents in the North Adriatic, diving activities were allowed by the platform legs only; HSE procedures strictly prohibit any activities in the water outside the platform itself. The research concludes that the platform actually has a positive impact due to the fact that it increases the biodiversity at the site.

This area is an important habitat for sea turtles (Lazar *et al.*, 2004), one of the most common random catches in various types of fishing gear in all of the world's seas. The incidental catches in the north-eastern Adriatic Sea amount to 2,135–4,334 catches per year. Considering the fact that fishery is forbidden around the platforms and pipelines, these areas represent good shelter for sea turtles. After exploitation is completed, some parts of the infrastructure (pipelines, platforms) will probably be removed. The dynamics of removal will be set by project documentation for this phase. But in case of high expenses it is recommended to leave some parts of the infrastructure to act as a shelter for living organisms. This role was confirmed during the study of the seabed near the gas pipeline, when the presence of sea turtles was recorded. If the installations are allowed to remain they can contribute in a positive way as biodiversity spots and shelters for endangered sea organisms.

Issues with the processing of formation water

For the two platforms studied, formation water was processed. However, the logical question that emerges is *why apply formation water processing if it already satisfies the requirements of the Barcelona Convention?*

The first answer is easy – since the Adriatic Basin is semi-closed, it is necessary to minimise all the risks that can appear, especially if you can apply low-cost technology.

The second answer requires some experience with stakeholders that consider these projects as something that can "endanger the environment". Of course, any project represents some kind of risk to the environment, and in spite of monitoring results, it would be irresponsible to claim there is no risk. Only approaches that ensure the minimisation of environmental risks and transparent presentation toward stakeholders in the public, fishery, mariculture, tourism, etc., can ensure trust and enable the smoother performance of similar projects in the future.

Figure 4: Photograph of marine life around platform (Oikon, 2011).

Figure 5: Marine turtle observed around platform (Oikon, 2011).

Conclusions

The Adriatic Sea is a semi-closed basin, and although exploitation activities have not been reported to have a significant environmental impact, it is necessary to confirm this through research. Favourable circumstances are the facts that the reservoir is shallow and gas is biogenic without higher hydrocarbons. This has enabled the application of relatively low-cost technologies: water-based drilling fluid and gravity separation for processing of formation water.

Decommission activities are an important part of each exploitation activity. But the real question is whether companies are generally ready to perform it. Some infrastructure will be probably removed, even reused as secondary raw material. But what about costs – is it possible to decrease them? A possible answer offered in this paper is leaving parts of the infrastructure in place, primarily exploitation platforms, repurposing them as artificial reefs that can have a positive impact on biodiversity. Of course, before this kind of decision, appropriate survey activities should be done for each location.

The risk of releasing unprocessed formation water appears to be low as the concentration of hydrocarbons is low, processing is carried out to minimise such risks and ensure that the trust of stakeholders is deserved. The numerical simulation and laboratory testing investigated confirmed that exploitation of biogenic gas from Plio-Quaternary sediments in the North Adriatic offshore is an environmentally low-risk activity.

Oil and gas production in Croatia is in continuous decline, and in order to maintain a certain level of production, it is necessary to perform new exploration activities. New targets – deeper formations – require different technology than that used presently, which may represent a bigger environmental risk. So this project is a good representation that with good planning of exploration and exploitation activities along with the application of know-how and a multidisciplinary approach, environmental risks can be minimised.

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Oil seep detection based on historical and recent satellite SAR data and manual interpretation: Eratosthenes Seamount (ESM): a very shy oil-trap candidate?

*Clément Blaizot**

For many years, remote sensing has been more and more widely accepted by geoscientists as a useful tool in the early stages of exploration campaigns to unveil natural oil seepages. Today, European programs such as SENTINEL allow us to retrieve an increasing amount of free and up-to-date SAR satellite data. By combining archives data, recent data and manual interpretation, our seep study discovered evidence of natural seeps present on both edges of the Levantine Basin, still waiting to deliver its first barrels of oil, despite gigantic nearby gas discoveries.

Pendant de nombreuses années, la télédétection a été de plus en plus largement acceptée par les spécialistes des Geosciences en tant qu'outil utile, au début des campagnes d'exploration, pour repérer les fuites de pétrole naturel. Aujourd'hui, les programmes européens tels que SENTINEL nous permettent de reconsulter une quantité croissante de données satellitaires (SAR), gratuites et mises à jour. En combinant les données archivées, les données récentes et leur interprétation manuelle, notre étude de fuite a mis en évidence des fuites naturelles de pétrole sur les deux bords du Bassin Levantin, toujours en attente de fournir ses premiers barrils de pétrole, malgré les découvertes proches et très importantes de gas, à proximité.

Durante muchos años, la teledetección ha sido ampliamente aceptada por los geólogos como una herramienta útil para descubrir filtraciones naturales de petróleo durante la etapa temprana de las campañas de exploración. Hoy en día, programas europeos como SENTINEL nos permiten obtener una gran cantidad de datos satelitales SAR gratuitos y actualizados. Al combinar datos de archivos, datos recientes e interpretación manual, nuestro estudio de filtración descubrió la evidencia de filtraciones naturales presentes en los dos extremos de la cuenca levantina, pese a la increíble cantidad de gas natural descubierto en esta zona, todavía no se ha extraído petróleo.

Seep hunting, like many other oil & gas disciplines, is a highly interpretative technique mainly because of the difficulty of discriminating natural seepages rising from the seafloor (seeps) from pollution (spills). Another often underestimated challenge is posed by what shall be nicknamed “lookalikes”: algal blooms, reefs, atmospheric bubbles, oceanic or wave artefacts, etc. Nevertheless, even if natural seepages uncover only a *clue* rather than the entire *crime scene* (where to drill!) in the full exploration investigation chain, seeps still remain a trustworthy *witness* of an active petroleum system and seep locations can indicate the edges of efficient vertical or lateral migration routes.

As described by Pajot (2013), Synthetic Aperture Radar (SAR) data is commonly accepted to be a handy and efficient way to perform seeps studies. One fast and cost-effective solution was to gather archived SAR data from around 1990 to about 2010. However, today’s European programs such as SENTINEL enable us to reach another landmark by adding recent data to baselines belonging to the past. Provided one is capable of processing the raw images delivered by the European Space Agency (ESA), it is almost free of charge to quickly collect a large set of different SAR images on an area of interest for the last 25 years.

This innovative approach relies on the coupling of archive data – which can first highlight small specific zones of potential within very large areas of up to 1,000,000 km² or more – with brand new data acquired just days or weeks ago, which can confirm the initial potential.

Seep interpretation heavily relies on the person seated behind the computer. In a time of Big Data, where the oil industry is benefitting from the progress of Artificial Intelligence and Machine Learning, there is still a point to be made by promoting the benefits of manual interpretation. Seep detection has little to do with binary concerns, it is never all true or all wrong: it is often “in-between” and in the end, it is all in the eyes of someone who has seen seeps around the world in several different contexts and that person’s ability to observe “weak signals”, where seeps might not be obvious at first glance. If we are not able to trust computers to make automatic interpretations, how can we help humans to become more accurate? One of the answers might be found in the accumulation of large sets of SAR data alongside a methodology that emphasises the recurrences of active seeps over time rather than the seep itself.

“The Devil is in the detail”

Seep hunting is like every classical hunt or angling expedition. There will be the easy catches and the fierce prey. Some seeps bear very significant features (morphology, radiometry, contours and context) whereas

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others are very tricky to detect. In addition, pollution and lookalikes play their parts in making the interpretation harder. Uncertainty is part of the game. However, seep interpreters have got two main assets at their disposal: their eyes and geo-statistics.

- Their eyes, because over the years, the interpreter gets used to favourable and unlikely contexts surrounding the seeps.
- Geo-statistics, because it helps to reduce the risk of misclassification of a seep, a spill and a lookalike. If it might sound erroneous to pretend that lightning never strikes twice in the same place, it is reasonable to claim that one will not misinterpret two or three times in the very same place. Interpreters should allow themselves some boldness in seep selection (which does not mean turning an obvious occurrence of pollution into a seep).

To be fair to the remaining dubious seep study detractors among the geoscience community, seep studies sometimes fail to make the mark because of two connected reasons: lack of data coverage and spills (pollution) being ranked as natural oil leakages.

Some seep detection methodologies rely on very small datasets (0-10 images for every X/Y of study zone). These methodologies have some limits, as it is doubtful practice to claim to give a reliable assessment of the potential of an area based on such a sparse dataset and it can also lead to a second issue: pollution being confused with natural oil seepages. Due to missing data coverage, the interpreter will not be fully aware of the natural conditions and local context of the interpreted SAR images on the study zone, be it natural phenomena such as swell, algae or bathymetry or anthropogenic factors such as boat presence, shipping routes or rigs.

The methodology of this study is based on the gathering of a large dataset and therefore it helps to flag shipping routes. Then, when there is an identified shipping route on the surface, the interpreter wisely tends to be more cautious in his/her interpretation.

Chase recurrence and weak signals

By selecting large sets of SAR images taken at different dates, with more than 100 images for every X/Y location of the study zone, a reliable analysis of the potential of an area becomes possible and the recurrence of the seepages in the same place can be highlighted.

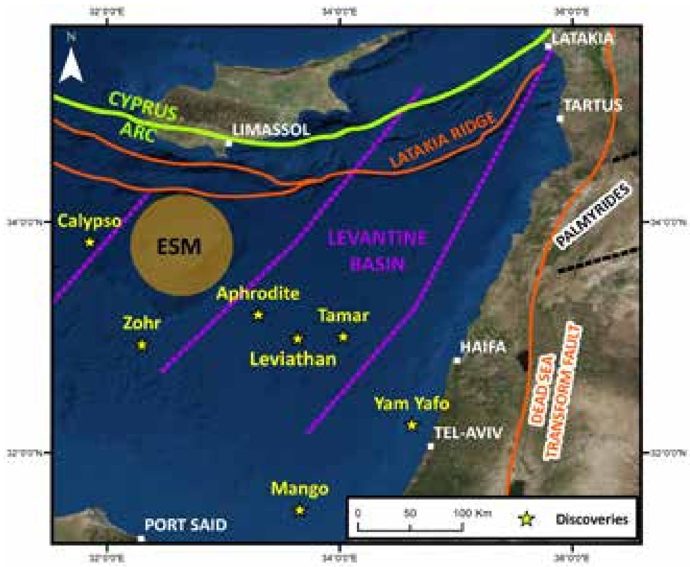

Figure 1: Levantine Basin, Eratosthenes Seamount (ESM) and discoveries.

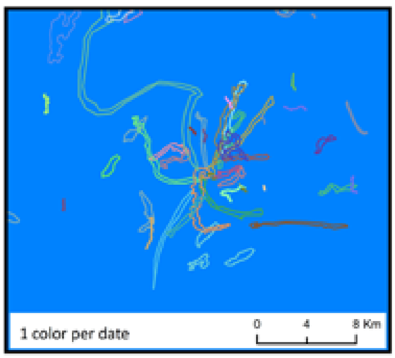

Figure 2: Seep anomaly on the eastern side of the Levantine Basin around the Latakia Ridge.

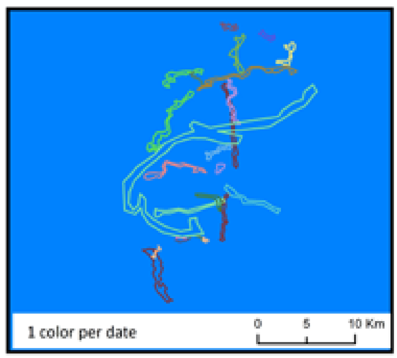

Figure 3: Seep anomaly on the western side of the Levantine Basin.

SAR imagery can detect objects with low roughness on the sea surface. However, many external factors can interfere with seep interpretation: currents, waves, swell, pollution. Our expertise is based on the manual discrimination between seeps, spills and lookalikes by paying close attention to the context of the interpreted objects.

Spills (pollution) often appear with very low radiometry on an SAR image (SAR (radar) data, unlike optical data, contains only black, grey and white pixels; low radiometry characterises an object having black pixels, while high radiometry will tend to feature white pixels). Indeed, ships tend to discharge significant amounts of oil directly on the sea surface, without any travel between sea surface and seafloor. In contrast, seeps rise through the whole water column: the journey between oil's origin on the seafloor and where it lies on the sea surface was documented in great detail by Jatiault *et al.* (2018). Considering the distance between the departure point and the destination point, it should be no surprise that seepages sometimes appear with higher radiometry and more diffused edges compared to pollution.

In short, one should not be misled by the radiometry of a seep: it's all about the context, sea conditions on the image and the presence of lookalikes.

Overview of the history of the Levantine Basin Seeps and its present contribution

Long before satellites were launched or even thought about, the Levantine region (***Figure 1***) appears to have hosted one of the first human encounters with seepages, dating back as far as 2000 BC and the famous bitumen from the Dead Sea, mainly used for boat caulking.

At the beginning of the 20th century, the comprehensive Report III of the Federal Oil Conservation Board of the United States (FOCB, 1928) had already traced records of onshore oil seepages in Syria. Very close to the sea between the towns of Latakia and Aleppo, asphalt made with Upper Cretaceous limestones and marls was found by locals. Furthermore, some petroleum appeared to seep out near the city of Latakia and live oil has been found in the Upper Jurassic to Upper Cretaceous carbonate series of Latakia 1 and 2 wells drilled close to the city (Bowman & Jensen, 2011). Roberts & Peace (2007) report plenty of offshore seepages in the East Mediterranean Sea linked to oil migration pathways. Bowman (2011) mentions repeated oil seeps on the Latakia Ridge, the Thrust and Fold Belt limiting the northern European plate.

It is therefore no real headline that natural oil is heavily seeping offshore on the eastern edge of the Levantine Basin. The Aphrodite, Leviathan and Tamar discoveries stand out as massive reminders that the centre of the basin is clearly gas-prone. Those discoveries have regenerated vivid interest in the region (Skiple *et al.*, 2012).

This study confirms the presence of numerous (35) recurrent (28 different dates from 2008 to 2017) and concentrated natural oil seepages forming a "star-shape" anomaly within the Latakia Ridge area (***Figure 2***).

This seep anomaly on the eastern flank of the Levantine basin is a striking example of the Holy Grail of seep interpretation: numerous, concentrated and recurrent seeps at the same location, various orientations, superimpositions, characteristic morphologies, fair bathymetry, low direct pollution context and a "star-shaped structure" with one clear emission point.

The present study also identifies very interesting concentrated seeps on the Western side of the Levantine Basin (***Figure 3***). Here, the seep anomaly is more enigmatic and relies on the importance of collecting many different SAR radar scenes. It highlights the advantages of the methodology based on the coupling of archival data and new Sentinel data. Archive data had already delivered evidence of some seeps that paved the way for an anomaly. SENTINEL data strengthened the first interpretation and boosted confidence in it. This anomaly also confirms how instrumental weak signals can be.

Seeps are numerous (24) and recurrent (17 different dates between 2008 and 2017). There is no clear emission point such as in the eastern side anomaly; however, seeps are concentrated and superimposed with various orientations, while the nearby local context is different to the otherwise relatively intense pollution observed within this part of the Mediterranean Sea. Some of the seep properties are weak and less distinct (***Figure 4***).

Unlikely from afar but far from being unlikely

There is no real definition of a beautiful seep in seep hunting. Only concentrated and accumulated seeps at many occasions in the same place matter. The seep on the left side of ***Figure 5***, located within the Eastern Levantine seep anomaly, displays all the classical characteristics of a seep and looks rather easy to detect compared to the tenuous and less perceptible seep on the right side of ***Figure 5***, located within the Western Levantine seep anomaly. What counts most: having one or two very characteristic unrepeated single seeps or having ten to twenty uncharacteristic repeating seeps? As seepages are part of active hydrocarbon systems, they should be repeating themselves over and over for an area to be rated as a hot prospect, regardless of the aesthetic side of the seepages.

Each seep is unique. Even by feeding computers with every seep characteristic or every image library, the issue of the context of a seep will remain the most decisive part of interpretation.

Eratosthenes Seamount (ESM), a sleeping giant?

According to the discoveries, at least two petroleum systems seem to be present in the Levantine Basin, which has been a major subsidence area since Triassic times and which could be roughly similar stratigraphically to the Palmyrides area in Syria from Triassic to Eocene. It is only in recent times (Neogene) and thanks to the progressive implementation of the Cyprus and Latakia accretion ridges that the Levantine basin became an important foredeep depocentre. One can note that apart from the above-mentioned onshore and offshore oil seeps, two kinds of fluids have been discovered and produced so far:

1. on the eastern and southern edges, the light oils of Mango 1 well in the

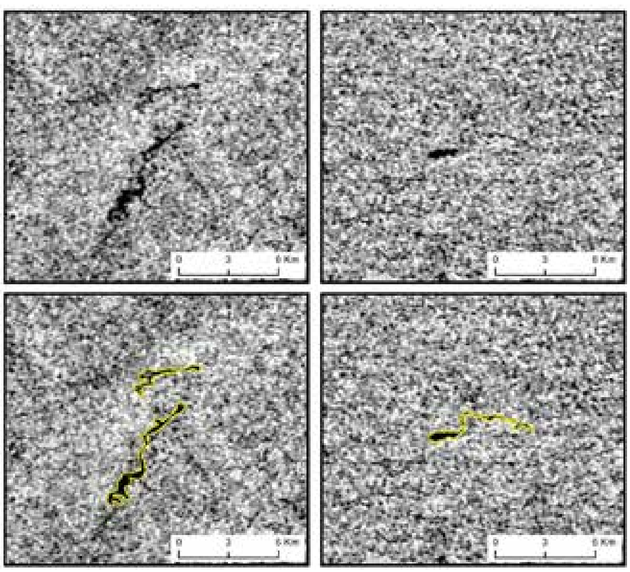

Figure 4: Selected illustrations of seeps on the Western side of the Levantine Basin (above: processed SAR image; below: SAR image with seep contours vectorised).

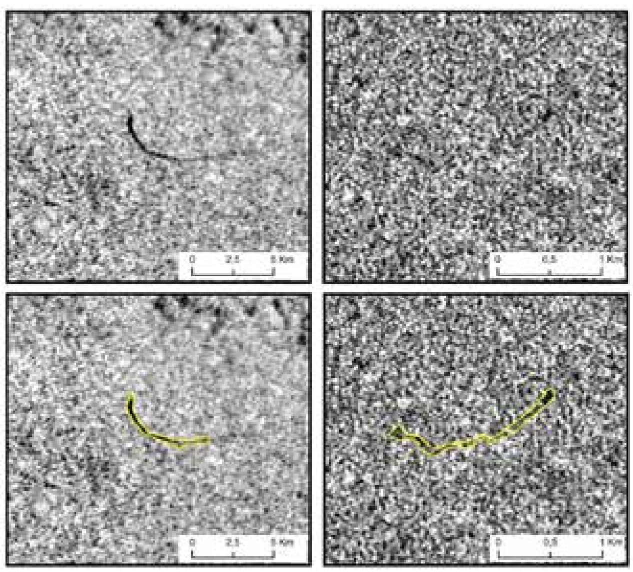

Figure 5: Selected illustrations of a seep in the Eastern (left) and the Western (right) Levantine Basin.

North Sinai Egyptian waters and of Yam-Yafo wells in Israeli waters have produced 8000 bopd in Cretaceous sands and 800 bopd, respectively. These oils are correlated either to the Triassic Amanus shale or the Upper Cretaceous shales (Barrier *et al.*, 2014).

2. very large gas discoveries have been made in the last decade in the centre of the basin, offshore of Israel, Cyprus and Egypt, leading to the rapid production of the Tamar and Zohr fields. This gas is thought to be of biogenic origin from the Mio-Pliocene rapidly subsiding series of the Levantine Basin in a low thermal flow context. However, one cannot rule out the possible existence of thermal gases generated from deep Mesozoic source rocks.

In fact, in such a context and whatever the origin of the gas might be, these extremely large quantities of recently generated gas will displace the oil from the centre of the basin to its very margins. This would be the reason why we see oil seeps on the eastern and southern edges of the Levantine basin. And what about the western edge? That is clearly where the prominent Eratosthenes Seamount proudly stands –one of the biggest structures in Europe, more than 4,000 square kilometres of structural four-way dip closure, and never drilled for hydrocarbons (***Figure 6***). This figure also hints at the similarities of gravity anomalies observed around the Calypso, Zohr and Leviathan discoveries and also at the Eratosthenes Seamount.

For the time being, only ODP leg 160 has begun to reveal the very nature and stratigraphy of this huge closure (Robertson, 1998). ODP leg 160 is made of 3 penetrations (sites 965-966-967) which have encountered shallow water carbonates in Santonian passing to deep sea carbonates in Maastrichtian and Eocene; then, an important uplift took place leading to an Oligocene hiatus, a Miocene shallow carbonates deposition and the subsequent very thin or non-deposition/erosion of Messinian salt followed by shale deposition in the Plio-Quaternary.

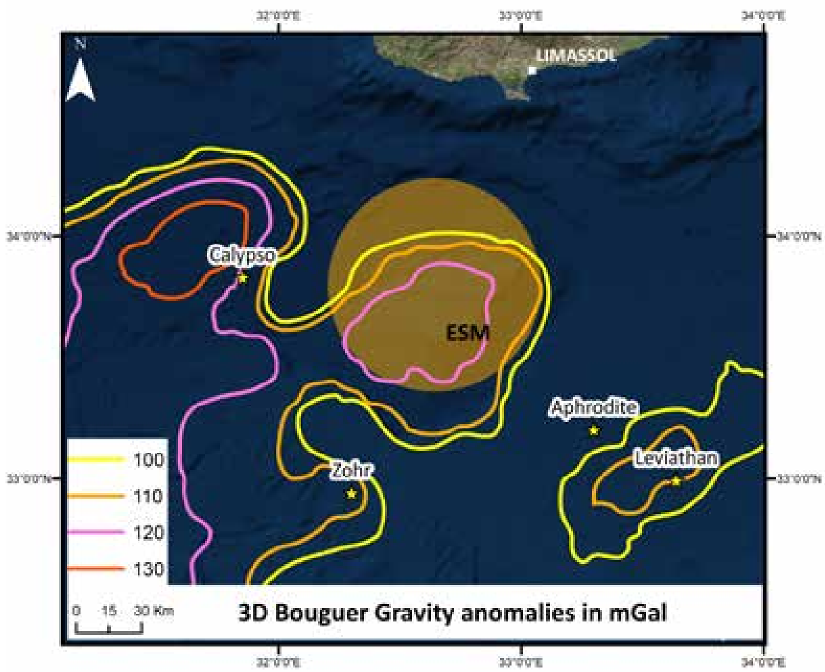

Figure 6: Bouger anomalies in Milligals (mGal) around the Eratosthenes Seamount (ESM),based on Chamot-Rooke et al., (2005)and retrieved from the Republic of Cyprus 3rd Licensing Round, and discoveries (yellow stars).

According to the few seismic sections available, it is clear that below the Upper Cretaceous series there still exist bedded seismic markers, witnesses of a possible thick (up to 3,000 m) Triassic to Lower Cretaceous sequence, which could host a similar petroleum system to the one identified offshore and onshore Syria, Israel or north-eastern Egypt.

Consequently, within the massive Eratosthenes structural closure, the main target might therefore be related to the efficient, Palmyrides-like, Triassic petroleum system that contains the Lower Triassic Amanus shale source-rock, the Middle Triassic Kurrachine dolomite reservoir capped by the Upper Triassic evaporites, such as that described by Barrier *et al.* (2014).

The presence of potential oil seeps in the vicinity corroborates the reality of today's oil migration from the adjacent Levantine

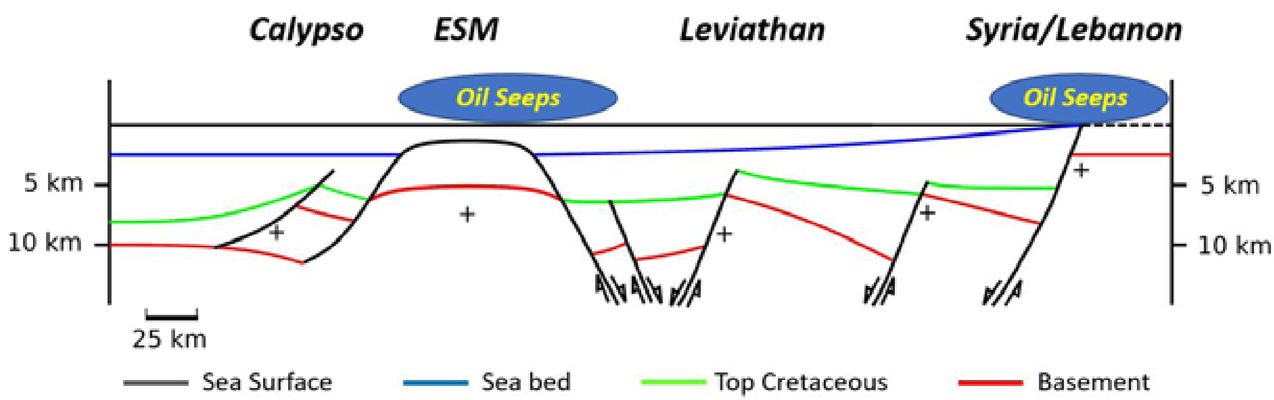

Figure 7: W-E structural sketched cross-section of the Levantine Basin, modified from Skiple et al., (2012) and according to Bouger anomalies from Chamot-Rooke et al. *(2005).*

Basin, as indicated in structural sketch ***Figure 7***.

The importance of (slightly) going against the flow

If nowadays *machine processing* seems to be stuck on every geoscientist's lips, then seep studies remind us of the importance of the *human process* that lies in hesitation, going back and forth, pondering and deciding.

Up to this day, how can a program make the distinction between a natural leakage and a lookalike when even a human interpreter feels unsure about it? Artificial Intelligence is an amazing tool perfectly suited to the detection of anthropogenic events, where the context is not as crucial as it is for natural events such as seeps.

Seep studies require various ingredients: gathering large sets of data, paying close attention to recurrence, welcoming "weak signals", performing manual interpretation and combining archival and recent data.

Data from geology and geophysics, as well as the presence of recurrent seeps within the Levantine Basin, confirm the Eratosthenes Seamount structure as an oil prospect. Based on this evidence, with potential confirmation from some more 3D geophysics surveys, the Eratosthenes Seamount structure deserves the drilling of exploration wells to see whether the nearby Leviathan gas-giant could be overshadowed by an Eratosthenes oil-monster.

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Numerical simulation of innovative fracking without water or chemical additives

*Michael Zhengmeng Hou and Faisal Mehmood**

Application of water-based fluids with chemical additives for fracking operations to increase the productivity of petroleum reservoirs has caused problems both environmentally and technically. Increased water consumption, water handling issues and induced seismicity have adverse impacts on environment. In addition, slowed flow-back and fracture closure, phase trapping and lower effective fracture lengths lead to less ultimate recovery. To address these issues, stimulation with light alkanes – i.e. waterless fracking without chemical additives – is proposed. This innovative waterless fracking not only minimizes the environmental risks but also results in increased ultimate recovery compared to conventional water-based fluids – especially in tight and ultra-tight reservoirs – due to its characteristics of rapid flowback and fracture closure, compatibility with the reservoir (no phase trapping) and increased effective fracture lengths.

L'utilisation de fluides aqueux comportant des additifs chimiques destinés aux opérations de fracturation hydraulique, pour augmenter la production de réservoirs pétroliers, est la source de problèmes concernant, à la fois, les domaines environnemental et technique. L'augmentation de La consommation d'eau, les problèmes de la gestion de l'eau et de la séismicité induite ont un impact négatif sur l'environnement. De plus, le ralentissement de l'écoulement du fluide et la fermeture des fractures, la non miscibilité des phases et la moindre continuité effective des fractures ont conduit, in fine, à une récupération plus réduite. Pour faire face à ces problèmes, une stimulation à partir d'alcanes légers - c'est à dire une fracturation sans eau et sans additifs chimiques - est proposée. Ce mode innovant de fracturation sans eau ne diminue pas seulement les risques environnementaux mais contribue aussi à une meilleure récupération finale - comparée à celle utilisant les fluides à composition aqueuse conventionnelle, spécialement en conditions de réservoir peu perméable voire étanche - la conséquence des conditions de rapide circulation et d'ouverture des fractures, compatibles avec le réservoir (pas de non miscibilité des phases) et augmentation effective de la continuité du système fracturé.

La utilización de fluidos basados en agua con aditivos químicos para operaciones de fracking con el objetivo de incrementar la productividad de las reservas de petróleo ha causado problemas medio ambientales y técnicos. El aumento del consumo de agua, los problemas con la gestión del agua y la sismicidad inducida tienen efectos adversos para el medio ambiente. Además, la reducción del flujo de retorno y el cierre de la fractura, la fase de captura y las longitudes de fractura menos efectivas conllevan una menor recuperación final.
Para abordar estos problemas, se propone la estimulación con alcanos ligeros, es decir, fracking sin el empleo de agua y sin aditivos químicos. Este innovador fracking sin agua no solo minimiza los riesgos medioambientales, sino que además aumenta la recuperación final en comparación con los fluidos convencionales basados en agua, especialmente en reservas estrechas y ultra herméticas, debido a sus características de rápido retorno y cierre de fractura, compatibilidad con la reserva (no fase de captura) y mayores longitudes de fractura efectivas.

Introduction

With ever increasing energy demands and the finite nature of conventional petroleum resources, the development of unconventional petroleum reservoirs has contributed to maintaining the balance between supply and demand. One example is tight sands and shale, which are produced using water-based fluid fracking. There has been an exponential increase in the shale gas production over the last decade in the United States, for instance. The use of hydraulic fracturing as a well-stimulation tech-

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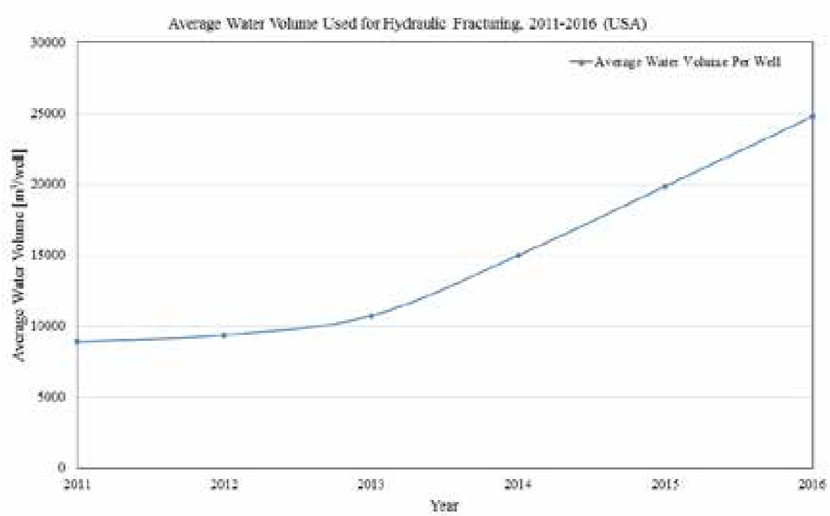

Figure 1: Increase in average water usage per well for hydraulic fracturing in the USA, 2011-2016 (Kohshour et al., 2016).

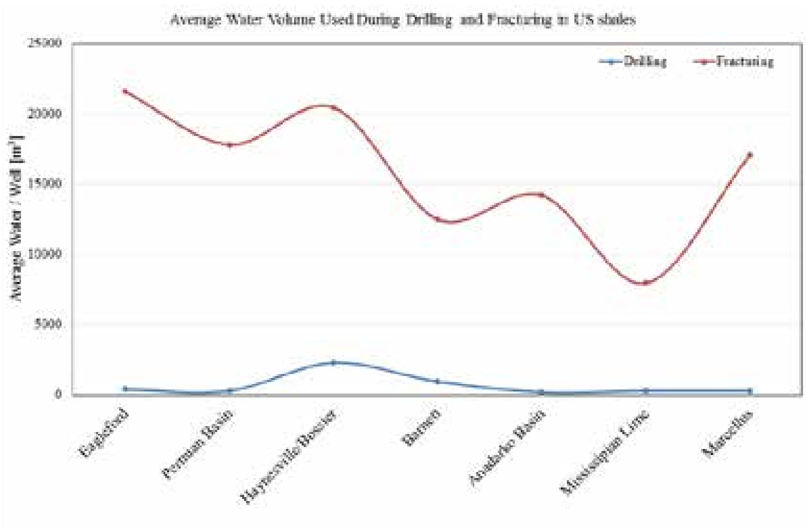

Figure 2: Water usage in drilling and fracturing in US shales (Kohshour et al., 2016).

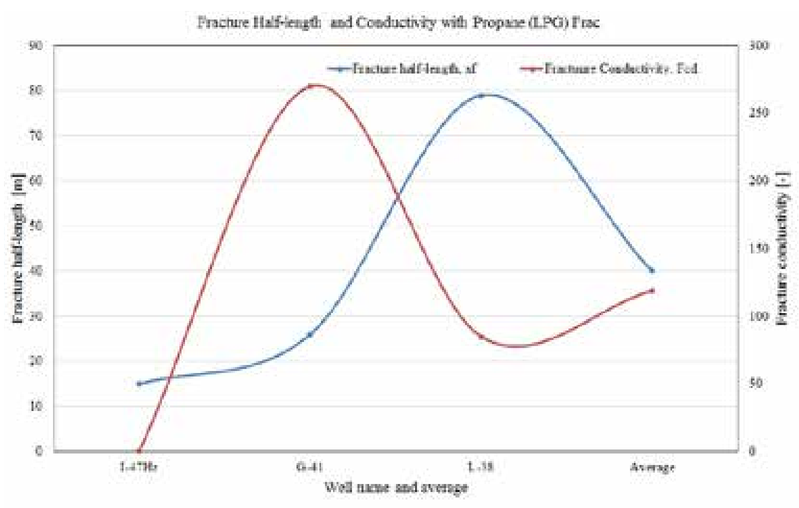

Figure 3: Fracture half-length and conductivity for propane fracking (LeBlanc et al., 2011).

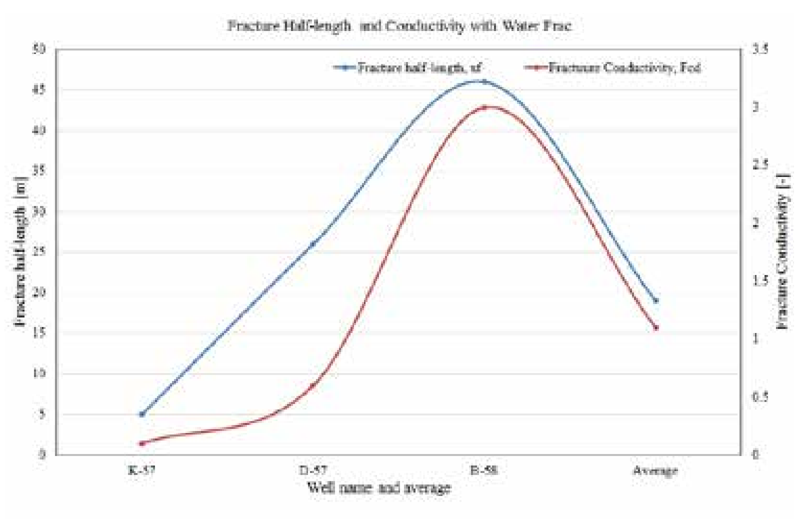

Figure 4: Fracture half-length and conductivity for water fracking (LeBlanc et al., 2011).

nique has triggered many concerns such as increased water consumption, water handling issues at the surface and induced seismicity leading to severe environmental problems (Kohshour *et al.*, 2016). Slowed flowback of water-based fluids results in delayed fracture closure and poor proppant placement, especially in the near perforation zone, and the flowback may continue for a year or longer, affecting recovery (LeBlanc *et al.*, 2011). Water trapping, especially in water sensitive clays, and sands with sub-irreducible water saturation have devastating effects upon relative permeabilities and hence on recovery (LeBlanc *et al.*, 2011). The fracture length and conductivity are also considerably lower for water-based fluids compared to waterless fracking fluids (LeBlanc *et al.*, 2011). The increased usage of water is a result of increased exploration and production activity and of multistage hydraulic fracturing, especially in unconventional reservoirs. The increased water usage on a per-well basis is shown in ***Figures 1*** and ***2*** (Kohshour *et al.*, 2016).

According to Rubinstein and Mahani (2015), waste water disposal (including the waste water from fracturing) is the main cause of recent increase in earthquakes.

There are many fracking fluids available today, including foam-based fluids (such as CO_2 based foams, alcohol based foams, oil based foams etc.), oil-based fluids (such as diesel), acid-based fluids, alcohol-based fluids, emulsion-based fluids and cryogenic fluids (such as liquid CO_2 and N_2) (Gandossi and Estorff, 2015). LeBlanc *et al.* (2011) presented a study of hydraulic fracturing in the McCully gas field (New Brunswick, Canada) with liquefied petroleum gas (LPG), mainly propane, as the fracking fluid. According to their findings, propane (LPG) fracking was more successful in the McCully field than the previously done water-based fracking. A comparison between LPG-based fractures and water-based fractures is provided in ***Figures 3*** and ***4*** (comparison based upon single fracture per well and comparable fracture job size). It is evident that the flowback of injected fluid in the case of propane-based fluid fracking was much quicker compared to water-based fluid fracking; the complete flowback of propane only took up to 10 days for all wells, whereas for water fracking it took more than a year for the complete flowback. Their results show a considerable increase in recovery from wells using propane-based fracking: around 1.5 times compared with water-based fracking and 3.8 times compared to when no fracking was carried out (LeBlanc *et al.*, 2011).

However, the problem with LPG-based fluid is the surface handling of propane, which exists as a gas at surface conditions and is highly flammable. In 2015, eCORP Stimulation Technologies, LLC introduced Light Alkanes Stimulation (LAS) using mineral oil for stimulation. From the phase behaviour of mineral oil (***Figure 5***), it becomes evident that at most reservoir conditions it will remain in liquid phase. Mineral oil normally has a density range between 800–850 kg/m[3], and because it may remain in liquid phase upon flowback, it is possible that its flowback may not be as quick as that of a gaseous phase.

The waterless fluids discussed above are either gas, which is difficult to handle at the surface, or liquid, which is denser and develops flowback issues. What would be ideal is a waterless fluid that can be handled as liquid at the surface – thereby giving the advantages of easier surface handling – and on its flowback after fracturing the target reservoir formation, it changes its phase to gas under low pressure wellbore (bottom-hole) conditions (such as after the nitrogen lift operation that reduces the hydrostatic pressure created by the fluid column) to add the advantage of quick flowback in the gaseous phase. Also, a complete numerical simulation of the multi-phase multi-component hydraulic fracture process is required with full3D software.

Proposed solution

The proposed fluid consists of light alkanes, but in this case even lighter components are chosen for fracking, such as alkanes (C_nH_{2n+2}) from C_5 to C_{10} including n-pentane, n-hexane, n-heptane, n-octane, n-nonane and n-decane, respectively. ***Figure 6*** shows the phase behaviour of the proposed fluid, which clearly shows that the proposed fluid will be in liquid phase at the surface and under high pressure fracturing conditions. The low pressure required in the wellbore and near wellbore regions for the fluid to change its phase at different reservoir temperatures upon flowback can be provided by the post fracture nitrogen lift operation and can also be observed in the ***figure 6***.

Alkanes (C_nH_{2n+2}) are naturally occurring hydrocarbons that are normally compatible with the reservoir fluids (hydrocarbons); therefore, the proposed fluid is likely to avoid phase trapping and formation damage, resulting in excellent flow efficiency of reservoir fluids. The density and viscosity of the proposed fluid are calculated using API standard correlations and presented in ***Figure 7***. The fluid may need to be gelled with guar (a naturally occurring compound also used in food) to enhance its proppant carrying abilities.

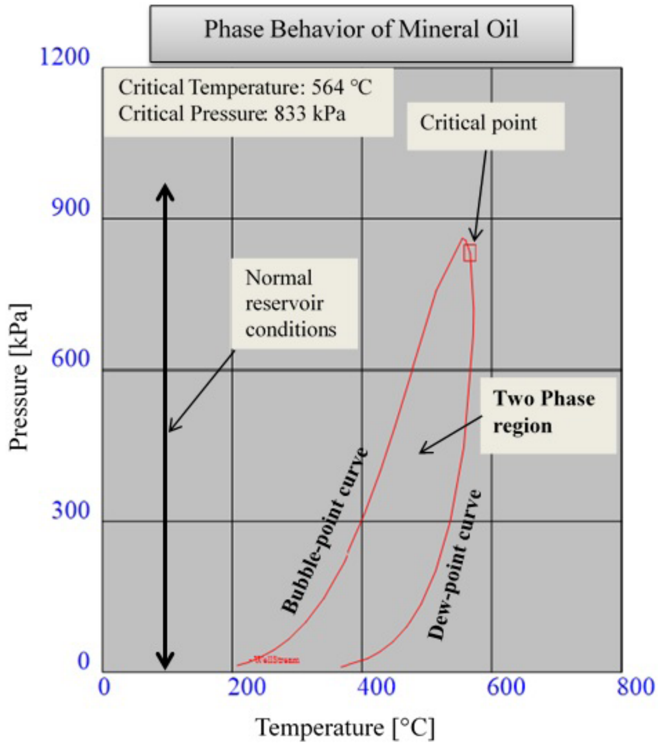

Figure 5: Phase behaviour of mineral oil (alkanes: C12–C35 (average), based upon literature study). Black arrow represents normal reservoir isothermal depletion conditions.

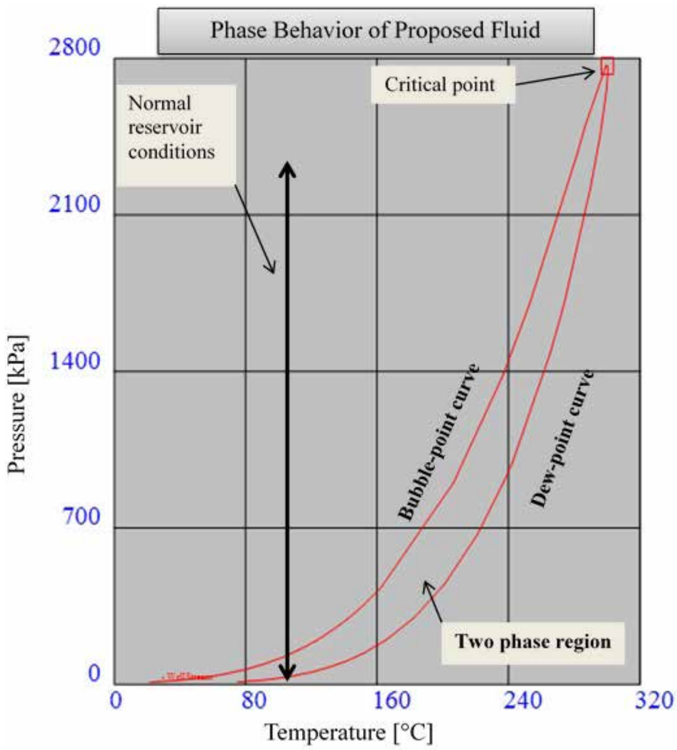

Figure 6: Phase behaviour of the proposed fluid. Black arrow represents normal reservoir isothermal depletion conditions.

After proppant placement, the gel breaks down, resulting in the original low-viscosity and low-density fluid. The phase change to gas will result in quick flowback and efficient proppant placement, especially in the upper part of the fracture, due to quick fracture closure. The fracking fluid can be recovered at the surface and utilised for other fracturing operations. Therefore, there is no need for special waste fluid handling at the surface for the proposed fluid, as the fluid is waterless and without

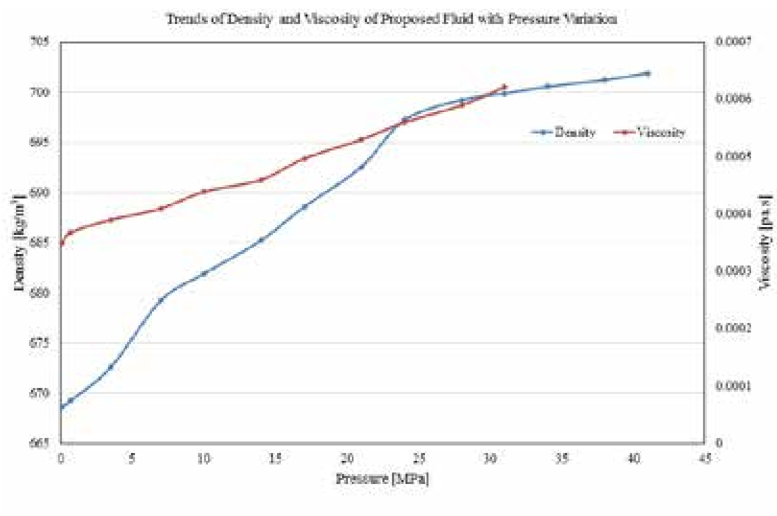

Figure 7: Density and viscosity trends of the proposed fluid.

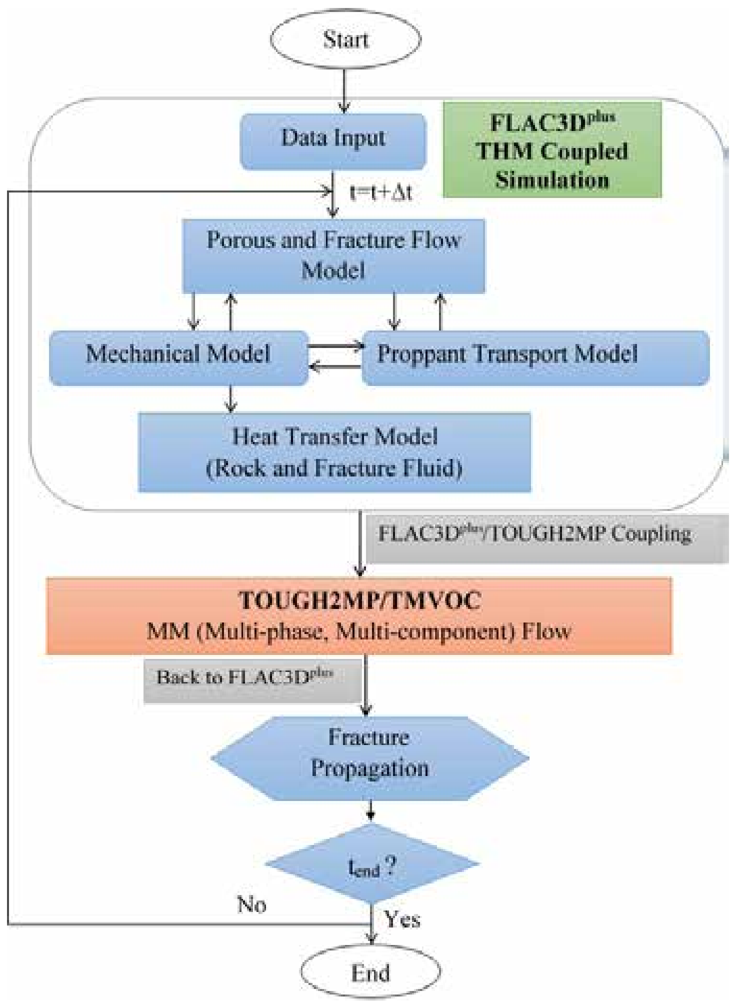

Figure 8: Flowchart showing the detailed methodology of complete numerical simulation.

chemical additives. Hence, the environmental risks associated with conventional fracking fluids can be greatly reduced with the added advantage of increased recovery. The re-use of injected fluid will also help to reduce the cost of fracturing.

Methodology

Numerical simulation is used to investigate the potential application of this innovative waterless light-alkane fracking fluid in a gas reservoir. The numerical simulation is performed by thermo-hydro-mechanical (THM) coupled FLAC3D^{plus}, an in-house upgraded version of FLAC3D. TOUGH2MP/TMVOC coupled with FLAC3D^{plus} can be utilized for multi-phase multi-component flow simulation (Gou *et al.*, 2015). ***Figure 8*** presents the detailed methodology in the form of flowchart. The following sub-sections provide brief details about the software.

FLAC3D^{plus}

FLAC3D (Fast Lagrangian Analysis of Continua in three Dimensions) is numerical modelling software utilised for geotechnical analysis. To make it an efficient numerical simulator for hydraulic fracturing, in-house improvements have been made. Zhou and Hou (2013) introduced a new approach based upon the novel idea of considering 3D stress state in a 3D geometric model for fracture propagation with a fully hydromechanical coupling effect and integrated it into FLAC3D, making it FLAC3D^{plus}. Zhou *et al.* (2014) developed a new constitutive model for the description of discontinuous displacement field due to fracturing phenomenon such as fracture enlargement, closure and contact. Gou *et al.* (2015) introduced a new coupling approach with consideration of hydro-mechanical (H^2M) coupled leak-off effects to couple multiphase multi-component flow simulator TOUGH2MP with FLAC3D^{plus}. Feng *et al.* (2016) introduced and implemented a new thermal module into FLAC3D^{plus} to numerically study heat transport and exchange during hydraulic fracturing between the fracture and neighbouring reservoir formations. Normally, Pseudo-3D models utilised in the industry only consider the minimum horizontal stress, whereas all principal (vertical, minimum horizontal and maximum horizontal) stresses are considered in FLAC3D^{plus}, making it a full 3D numerical simulator.

TOUGH2MP/TMVOC flow simulator

TMVOC (belonging to the family of the TOUGH2MP simulator) is a numerical simulator for multi-phase (three-phase) multi-component non-isothermal flow of hydrocarbons; it has the capability to simulate multi-phase hydrocarbon flow. The three phases include water, non-condensable gases (NCG) and non-aqueous phase liquids (NAPLs). The flow behaviour can be modelled for all combinations of three phases including a maximum of 8 gases, 18 NAPLs and water (Pruess and Batistelli, 2002).

To support the idea of new innovative fracking, first a flow simulation of proposed fluid is carried out to observe phase change using TOUGH2MP/TMVOC.

TOUGH2MP/TMVOC simulation on a fictive model

In the first phase of research, a fictive model for a gas reservoir is developed to observe the phase change of injected fluid. The model details are provided in ***Table 1***. Since the thickness of created vertical fractures is normally only a fraction of an inch, the model is given a small y-dimension of 0.5 m. Grid blocks with small width help to better understand the behaviour of the fracture as well as fluid flow in the model. A special high-temperature reservoir scenario (153 °C) is considered in the model to make its properties close to required wellbore and near wellbore formation conditions, such as those essential for phase change in fluid flowback as shown in ***Figure 6***.

It is a normal practice to opt for nitrogen lift operation after fracking for reduction of pressure in the wellbore (wellhead and bottom-hole) in order to ease the flowback of injected fluid. Our fictive model thus assumes a pressure of only 0.42 MPa in the near wellbore region. Initially, the proposed fluid is injected into the gas reservoir (fictive model) for a period of 10 hours at an injection rate of 2.7×10^{-3} kg/sec. A total of 97.2 kg of fluid is injected into the formation. Then the injection is stopped and injected fluid is allowed to change its phase under reservoir conditions. The simulation is performed for a period of fifteen days during which there is no production, so all of the fluid remains in the reservoir.

Table 1: Properties of fictive model.

Model dimensions	*10 m×0.5 m×10 m*
Number of grid blocks	*40×1×20 = 800*
Reservoir fluid	*Gas (methane 95 %, ethane 5 %)*
Depth	*2090 m*
Reservoir temperature	*153 °C*
Conditions in the near wellbore region after hydraulic fracturing to observe phase change:	
Pressure	*0.42 MPa*
Porosity	*35 %*
Permeability	*1.0×10^{-14} m^2*

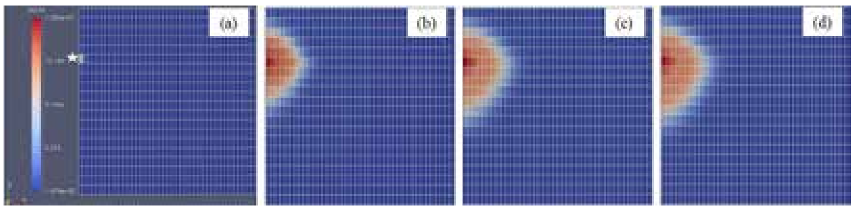

Figure 9: Increase in the density of gas phase due to phase change of injected fluid (DGAS: gas density), star placed against point of injection, (a) at the start of injection, (b) at the end of injection, (c) after 7 days of injection and (d) after 15 days of injection.

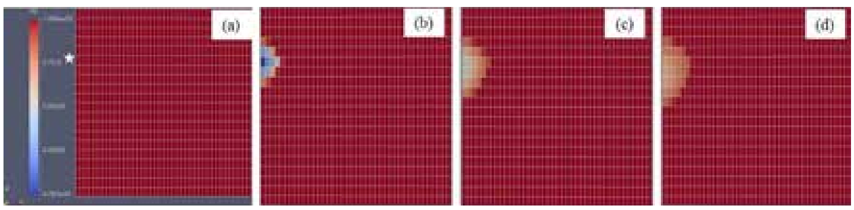

Figure 10: Increase in gas saturation due to the vaporisation of proposed injected fluid (SG: gas saturation), star placed against point of injection, (a) at the start of injection, (b) at the end of injection, (c) after 7 days of injection and (d) after 15 days of injection.

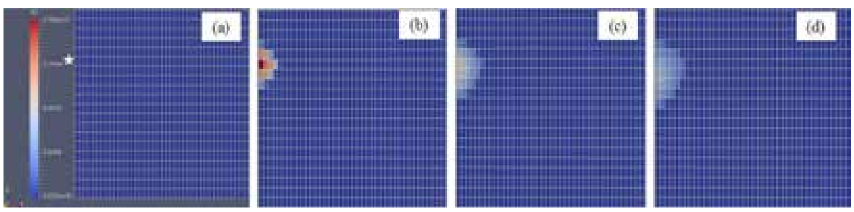

Figure 11: Decrease in the injected fluid saturation in liquid phase due to its disappearance into gaseous phase (SO: fluid saturation in liquid phase), star placed against point of injection, (a) at the start of injection, (b) at the end of injection, (c) after 7 days of injection and (d) after 15 days of injection.

Results and discussion

Based upon ***Figure 6***, the conditions for phase change in TOUGH2MP/TMVOC simulator are met in the fictive model and results can be observed from ***Figures 9–14.***

Change in density and saturation of injected fluid

Figure 9 represents the increase in the density of the gaseous phase with time. Initially the reservoir contains only reservoir gas; hence, at the given low pressure and high temperature near the wellbore region it has a density of only 1.979 kg/m^3. The proposed injected fluid starts to change its phase after coming in contact with the reservoir due to the pressure and temperature conditions of the reservoir. As components of the injected fluid vaporise, the gas density increases to a maximum of 15.56 kg/m^3. The large increase of 800 % in the density of gaseous phase is due to phase change of injected fluid.

Similar results can be observed from ***Figures 10 and 11***, showing the variation of injected fluid saturation in the gas and liquid phase, respectively. The increase in gas saturation indicates the phase change of injected fluid. At the end of injection (***Figure 10(b)***), the injected fluid in liquid phase can be observed in the blue to grey grid blocks (red grid blocks represent 100 % gas). However, at seven and fifteen days from injection (***Figure 10(c)*** and ***(d)***), it can be seen that the gas saturation has increased, especially in the zones which previously contained injected fluid in the liquid phase. ***Figure 11*** shows the injected fluid saturation in liquid phase from the start of injection until fifteen days after the injection. The injected fluid occupies the injection zone and other nearby zones in the liquid phase during injection. Later on, the decrease in liquid saturation from 99.5 % to between 50-25 % in different zones shows the disappearance of injected fluid into its gaseous phase (***Figure 11(c)*** and ***(d)***).

The complete phase change of the fluid is not observed in the current simulation because the assumed pressure and temperature in the model put the fluid in the two-phase region, as seen in ***Figure 6***. If the pressure is further reduced to the single phase gas condition as in Figure 6, the fluid will completely change its phase.

Change in the weight percent and moles of individual components of injected fluid in different phases

Figures 12 and ***13*** represent the change in the weight percent of individual components of the injected fluid in the gaseous and liquid phase respectively. As seen in ***Figure 12***, n-pentane shows the maximum phase change with around 50 weight percent in gaseous phase at the end of 15 days after injection. The increase in weight percent of components in the gaseous phase in ***Figure 12*** is confirmation of phase change.

Similarly, ***Figure 14*** shows the increase in the number of moles of individual components in the gaseous phase, presenting a similar trend as presented in ***Figure 12***. The heavier n-decane and n-nonane– with molecular weights of 128 and 142, respectively – show minimum phase change under current conditions due to their lower vapour pressures.

The phase change is quick initially and then slows down. Most of the phase change occurred within a period of two days.

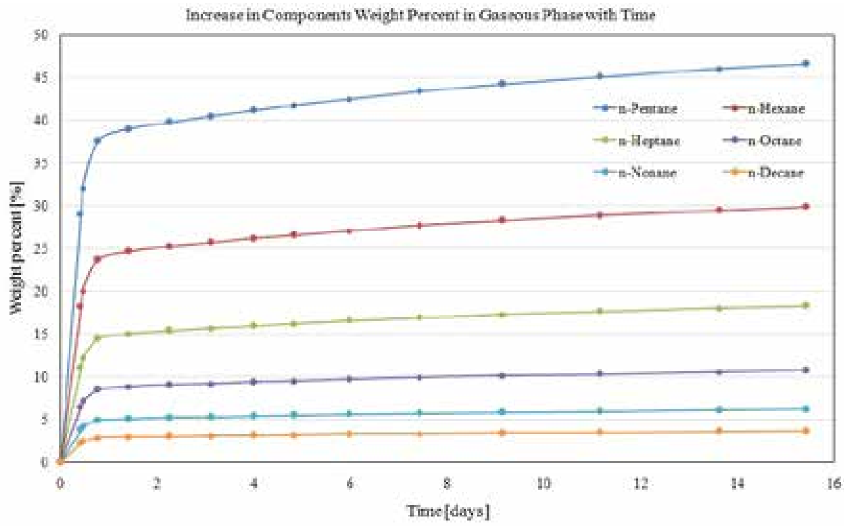

Figure 12: Increase in the weight percent of individual components of proposed injected fluid in gaseous phase with time.

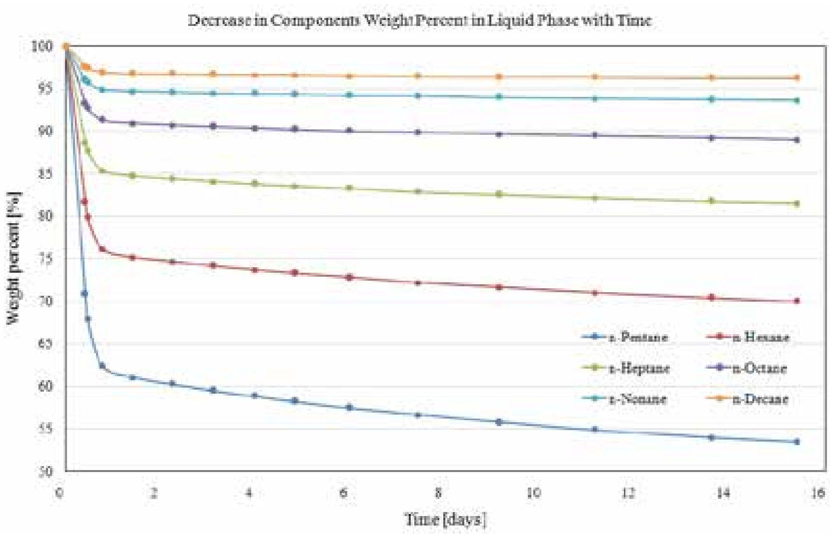

Figure 13: Decrease in the weight percent of individual components of proposed injected fluid in liquid phase with time.

Conclusions

Based upon obtained results (***Figures 9–14***), the fluid has the ability to change its phase from liquid to gas under low pressure. Therefore, maximum and quick flowback of injected fluid is possible.

The proposed fluid can be handled (through gelling, proppant mixing) with conventional surface equipment as it exists in liquid phase at normal surface conditions. However, care must be taken during surface handling because of the hydrocarbon's flammable nature.

Phase trapping can be avoided as proposed fluid has only light hydrocarbon components (n-alkanes, C_5-C_{10}), and is compatible and miscible with the reservoir hydrocarbons.

Upon flowback, the fracking fluid can be separated from reservoir fluid. The difference between the boiling point of butane and pentane is about 37 °C, so at surface conditions the injection fluid is expected to be separated as liquid. One possibility for separation is flow through a separator. Otherwise, a more complex system including a stripper plant or fluid refrigeration may be required. Once separated, it can be reused for further fracking operations. Fluid reuse for subsequent fracking operations will not only reduce the cost of operation, but could also make it comparable with water-based hydraulic fracturing costs, especially in areas of water scarcity.

The added advantage of increased ultimate recovery can make the economics of the proposed fluid reasonably attractive.

As the fluid consists of six components, from pentane to decane, it is possible to design a variety of compositions in terms of mole fraction of individual components based upon different encountered reservoir conditions. The mole fraction of heavier components can be increased for fracturing in reservoirs where reservoir temperature is higher (in excess of 130 °C) and vice versa so that the fluid can change its phase to gas upon flowback for faster clean-up.

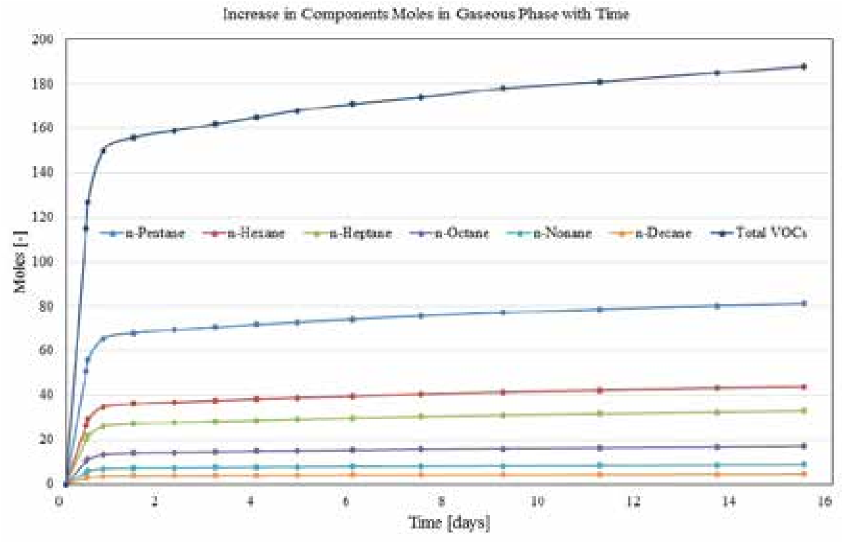

Figure 14: Increase in the number of moles of individual components of proposed injected fluid in gaseous phase.

Recommendations for future research

Future research will include a complete numerical simulation of a hydraulic fracture job; i.e. a coupled TOUGH2MP/TMVOC-FLAC3D^{plus} simulation. In addition, FLAC3D^{plus} can perform numerical simulation for incompressible fluids; improvements need to be made so that the thermo-hydro-mechanical processes of compressible fluids may be simulated. Moreover, an economic analysis needs to be performed for fracking with the proposed fluid before performing hydraulic fracturing in a real test case.

Acknowledgment

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Analysis of time-dependent filtration utilising measurements made on sandstone samples

Gyula Gábor Varga, Ágnes Fiser-Nagy and Tamás Fancsik*

When drilling a hydrocarbon well a quantity of the applied drilling fluid enters the formation through its pore system, and meanwhile the solid content forms a coating on the wellbore surface. This phenomenon (filtration) describes the reduction of initial permeability of the formation and thus lower productivity of the well. The investigation of the effect of drilling fluid on the formation is essential, since one of the main roles of the drilling fluid is to protect the productivity of the hydrocarbon bearing formation. While the API standard filtration tests cannot provide information about the permeability alteration caused by the drilling fluid, our new method is capable of doing so. The measurements are applied on standard core plugs of comparable petrophysical properties, under identical reservoir conditions. Besides determining the scale of permeability alteration, the main goal of the current investigation is the determination of the time dependency of filtration.

Lorsque l'on réalise un forage pétrolier, une quantité du fluide utilisé pour cette opération pénétre dans la formation lithologique grace à sa porosité naturelle et, pendant ce temps là, il y a création d'un revêtement solide, à la périphérie du puits. Ce phénomène (filtration) représente une diminution de la perméabilité initiale de la formation et réduit donc la production du puits. L'étude de l'effet produit par le fluide de forage sur la formation lithologique est essentiel puisque l'un des rôles majeurs du fluide de forage consiste à protéger la productivité de l'horizon producteur d'hydrocarbures. Tandis que les tests usuels API de filtration ne peuvent pas fournir d'information sur la dégradation de la perméabilité causée par le fluide de forage, notre nouvelle méthode est capable de le faire. Les mesures sont appliquées sur des échantillons compacts avec propriétés pétrophysiques comparables, sous des conditions de gisement, identiques. Au-delà de la détermination d'une échelle de l'altération de la perméabilité, le but principal de cette étude actuelle est de déterminer une échelle de temps versus le degré de filtration.

Cuando se perfora un pozo de hidrocarburos, una cantidad del fluido de perforación empleado se introduce en la formación a través de su sistema de poros, y al mismo tiempo, el contenido sólido forma un recubrimiento en la superficie del pozo. Este fenómeno (filtración) describe la reducción de la permeabilidad inicial de la formación y, por lo tanto, una menor productividad del pozo. La investigación del efecto del fluido de perforación en la formación es esencial, ya que una de las funciones principales del fluido de perforación es proteger la productividad de la formación de hidrocarburos. Si bien las pruebas de filtración estándar API no pueden proporcionar información sobre la alteración de la permeabilidad causada por el fluido de perforación, nuestro nuevo método es capaz de hacerlo. Las mediciones se aplican en tapones de núcleo estándar de propiedades petrofísicas comparables, en condiciones de depósito idénticas. Además de determinar la escala de alteración de la permeabilidad, el objetivo principal de la investigación actual es la determinación de la dependencia temporal de la filtración.

Introduction

Deep drilling is carried out for hydrocarbon research and/or production, in order to transfer hydrocarbons from the depths or to collect geological and reservoir information. Therefore, during the entire program, the presence of a pre-designed and appropriately adjusted drilling fluid is necessary. Drilling fluid is a physical, chemical and rheological substance which is largely liquid-based. Drilling mud must meet numerous expectations, as the drilling operation is a complex system with numerous interactions between the different components. The highly developed drilling technologies often need special fluids (Jayanth and Ziaja, 2011), which must ensure the transport of cuttings to the surface, cooling of drilling bit, lubrication of drill string, achievement of an anti-corrosion effect, protection of the hydrocarbon bearing formation and provision of adequate back pressure (Salih and Bilgesu, 2017). Beyond technical aspects, its effects on the environment must be kept to a minimum; furthermore, conditions such as economy and cost-effectiveness must also be met. It is clear, therefore, that drilling mud plays an important role during deep drilling process, since in addition to its primary task it might influence the forward speed of drilling, sticking of tool or fluid loss, as well. Well-chosen mud helps to overcome problems emerging during the process of drilling, such as instability of the open hole, torque decreasing or disintegration of cuttings (Al-Zubaidi *et al.*, 2017), which might aid well completion or cementing.

Among the criteria for the drilling fluid, besides the high priority of safety, is the minimisation of formation damage, particularly during operations in hydrocarbon bearing formations. Therefore, in drilling fluid design, formation damage minimisation must be enforced. During deep drilling a certain amount of outflowing drilling fluid enters the formation, and during this process it forms a thin low permeable layer on the wellbore called filter cake. In the cases of both overbalanced and balanced drilling, the fundamental problem is the extra costs from losing the filtrated drilling fluid as mud losses; furthermore, production capacity of the well is reduced by mud contamination. Since filtration will take place in any event, during operation process the aim is to minimise the damage caused by outflowing mud. The performance and extent of formation damage can be controlled and verified by filtration analysis.

Typically, filtration analysis takes place on test materials such as filter paper or ceramic discs. However, it must be considered that the results from this kind of tests do not take the characteristics of the geological

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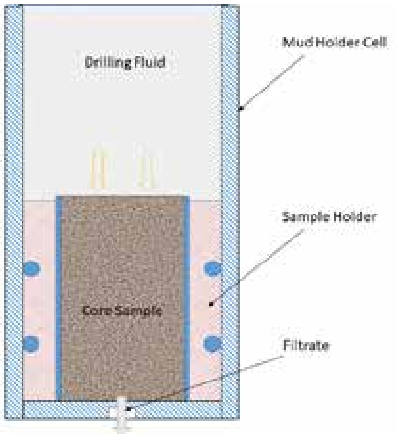

Figure 1: The invented measuring cell with the inner core sample holder compatible with the OFITE 17-50-1 apparatus.

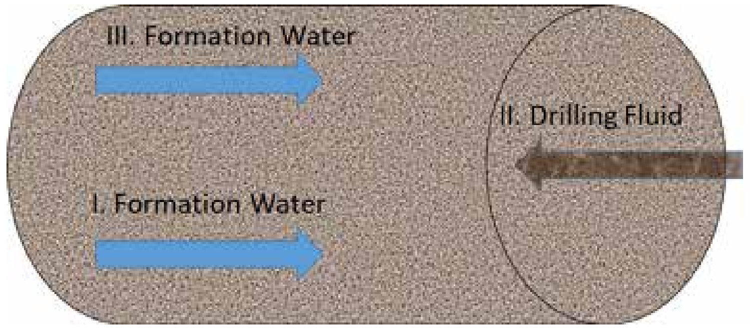

Figure 2: Schematic figure of the measurement process on the natural core sample (d= 3.75 cm).

formation into account. Thus, in such cases the test could be misleading, since it inadequately simulates bottom-hole conditions.

We have developed a new method to increase knowledge of the process of filtration phenomena. The essence of this work is to carry out filtration test on a real natural core sample instead of model media. This is the reason why we designed a new measuring cell, to allow measurements to be made on plugs used in oil industry. The main advantage of this newly invented measurement method is that it providesthe opportunity to examine the rate of permeability degradation caused by mud contamination besides the standard data obtained.

The intention in the present study is to explore the time dependence of both the filtration process and the formation damage. This may be helpful in order to develop a uniform measurement protocol for filtration tests implemented on core plugs, as well as providing information that could lead to a better understanding on the impact of drilling fluid on the formation under bottom-hole conditions.

Methods

Filtration Measurement

According to the literature and common practice the filtration test is carried out on filter paper or a ceramic disk. The API standard Fluid Loss Test can be performed at both low temperature and low pressure (LTLP) and high temperature and high pressure (HTHP) conditions. The LTLP test runs with ambient temperature fluid and 100 psi differential pressure, while the HTHP test runs with optional parameters modelling the bottom-hole conditions. A standard filtration test apparatus can heat the drilling fluid up to 149 ˚C (300 ˚F), but normally the test runs at T = 65 ˚C (150 ˚F); while the differential pressure is usually 34.74 bar (500 psi). The duration of a filtration test is 30 minutes in both low and high circumstances with filtration paper or a ceramic disc. If the tested drilling fluid has proper fluid loss features, at the end of the measurement a thin (maximum 2 mm thickness) non-permeable filter cake evolves on the surface of the model medium (filtration paper or ceramic disk) (API RP 13-B-1).

Although the standard filtration test is widespread and provides quick and reliable basic information about the filtration volume, it has some well-known disadvantages as well. Neither the filter paper nor the ceramic disc can model the real rocks around the wellbore. The real bottom-hole conditions are difficult to reproduce: the in-situ permeability, porosity, saturation and pore-size distribution can never be modelled using conventional procedures. While conventional procedures are a useful and simple solution for the mud engineer to describe and comparethe behaviour of different muds under lab conditions, they cannot represent real cases. Hence, a new method is required to reach a better estimation of filtration volume, to predict the formation damage, and to obtain more information about the behaviour of the drilling fluid on bottom-hole conditions.

Therefore, a new measurement procedure was developed (Varga *et al.*, 2018); the essence of it is to use real rock samples instead of filtration paper or ceramic disks. In that way not only will the filtration volume represent values closer to the real wellbore values, but data on formation damage will also be available for examination by repeating the permeability measurement after mud contamination (Rahman and Marx 1991; Jiao and Sharma 1992; Liu and Civan 1994).

A new inner sample holder was invented and a new mud holder cell was designed to be compatible with the conventional OFITE 17-50-1 apparatus. The tester itself was slightly modified as well: a longer primary shaft was needed in order to permit the measurement of longer cells, as core samples are thicker than the conventional filter paper or ceramic disc. The core sample dimensions were the following:

- Length: 70 mm (2.76") with a tolerance of ±1 mm or ±0.04"
- Diameter: 37 mm (1.46") with a tolerance of ±0.5 mm or ±0.02"

The construction of the sample holder and the modified cell can be seen in ***Figure 1***.

As the traditional core plugs used in the oil industry fit into the new inner sample holder, the samples can be used without any further preparation needed after performing the basic petrophysical measurements (porosity, absolute and effective permeability).

Figure 2 illustrates the procedure of a filtration test on a core plug. After the porosity and absolute permeability values (measured by gas) are determined, the sample is saturated by artificial formation brine, then the effective permeability measurement is carried out (Stage I) according to the API-RP 40 standards. In the second step the filtration test is carried out with the flow of drilling fluid in the opposite direction, as occurs in a real bore hole. In the last step (Stage III) the permeability of the contaminated sample is measured with artificial formation water in the same flow direction as in the first step in order to determine the permeability reduction caused by the drilling fluid.

As we wanted to simulate bottom-hole

Table 1: Additives of water based drilling mud.

Materials	Quantity gram/liter
Bentonite	35
NaOH	1
CMC CP030	5
CMC CP5000	1
Gypsum	15
Polydrill	4
Polythin	3
Barite	400

Table 2: Rheological parameters of the drilling fluid (25 ˚C; 1012 mbar).

Property	Values	Units
Density	1.30 (10.85)	kg/dm³ (ppg)
Plastic viscosity	37	cp
Yield point	41	lb/100 ft²
10 s gel strength	3	lb/100 ft²
10 min. gel strength	6	lb/100 ft²

conditions, the test was run at formation temperature (94 ˚C; 201.2 ˚F) and 15 bar (217.55 psi) differential pressure in static state. These conditions are present when drilling a common hydrocarbon bearing formation or at a static open hole.

Drilling fluid

For the filtration tests the drilling fluid was prepared in the laboratory according to the recipe shown in ***Table 1***. First the necessary water was measured into the mixing tank, then the necessary amount of barite and bentonite was added with continuous mixing at a rate of 15-20 g/min. After adding the caustic soda (dissolved in advance) and the remaining additives, the fluid was mixed for 30 minutes by a Chandler Engineering 30-70-1 mixer at a speed of 4000 s^{-1}.

The basic rheological examinations were carried out on the mixed fluid (API RP 13-B-1), at ambient temperature (22 ˚C; 71.6 ˚F) and atmospheric pressure (1012 mbar; 14.68 psi) by a Fann 35 rotational viscometer (***Table 2***).

Natural Core Samples

The finely distributed quartz-rich sandstone core samples originate from a Hungarian sedimentary basin, from the depth of 1,900-2,100 m (6,233-6,890 ft). The cores should be made uniform for normal permeability measurements. The core samples are drilled out from the original core and are prepared for measurement. The flow direction for the permeability tests was selected according to the normal flow direction in in-situ conditions. In the course of the sample selection the aim was to create a group of core plugs with similar petrophysical properties (porosity and permeability), especially effective permeability (measured by artificial formation brine). The porosity and permeability measurements followed the normal API standard procedures (API RP 40). The selected samples are listed with their petrophysical parameters in ***Table 3***. All samples belong to a permeability interval of 697–936 mD, which are considered very high values, so that the permeability degradation caused by the contamination of the drilling fluid would be more evident. The number of the selected samples is not suitable for a statistical examination; nevertheless, the aim of the recent investigations is to examine the time dependence of the permeability decrease by the filtration test in order to set up a proposal for the optimal measurement protocol.

The samples are in a tight interval of petrophysical properties (porosity and permeabilities), although naturally the values are not identical. The similarity in properties makes it possible to compare measurements carried out in different time frames. The time needed for filtration through a sample depends on the wet porosity volume ($V_{pore(wet)}$) of the sample, and this parameter was used to determine the necessary time intervals for each measurement. Accordingly, the longest time frame was the necessary time to produce filtration volume, which is the equivalent of 100% wet porosity volume (Sample 1 was used). Then the measurements were run for the time frames of $V_{pore(wet)}$ = 75%, 50% and 25% equivalent filtration volume on the remaining samples.

Results and discussion

Compared to the previous measuremnts (Varga *et al.*, 2018) carried out in lab conditions (API RP 13-B-1), in this study formation temperature and deferential pressure conditions were applied that match the characteristics in the bore hole. This led to results better reflecting real conditions prevailing during the drilling process.

The results of the filtration tests are shown in ***Figure 3*** in terms of the filtration volume as a function of measuring time for core plugs and filter paper. The standard filtration test with filter paper was run for 30 minutes at 6.97 bar (100 psi) pressure and 25 ˚C (77 ˚F) temperature. The resulting filtration volume (5.7 ml) is valid for the 9 cm (3.54") diameter, which has to be converted to the core plug diameter 3.75 cm ± 0.05 cm (1.476" ±0.02"). The filtration volume of the filter paper with this conversion (0.96 ml) is now comparable to the core plug results.

As ***Figure 3*** presents, the curves of the filtration volume have two sections in both cases: an initial, steeply increasing section, and after a breakpoint a moderately and evenly increasing second section begins. The initial part of the curve represents the spurt loss phenomenon, when the drilling fluid passes unhindered through the filter media because of the lack of filter cake. In that part of the measurement, the filter cake does not exist or is in a very primitive state and is unable to prevent the drilling fluid from permeating the medium. The breakpoint of the curve is the starting point of the state change, when the filter cake starts to become impermeable and is able to restrain the drilling fluid. The second section of the filtration volume curve represents the stabilised low fluid flow through the filter cake and the filter media.

In the case of the core plug, these stages occur at a slower rate compared to the filter paper. W ith the filter paper the development of the filter cake is quite fast, so the break point of the curve appears basically right after the beginning of the measurement (***Figure 3***), while for the core plug this process is much slower. The most presumable cause of this phenomenon is the difference between the filter media. The core sample has a significant volume with a certain percentage of pore volume which is a quite appropriate flowing channel for even the dry matter of the drilling fluid. Thus, the core plug is acting like a buffer zone until the filter cake becomes mature enough to prohibit the drilling fluid from entering the core in a significant amount. The visual observation of the filtration volume (***Figure 4***) helps to confirm this phenomenon, since the initial fluid flowing through the sample came with a notable amount of dry matter derived from the drilling fluid. With time, the filtration volume clears up, showing the sealing effect of the filter cake. However, it

Table 3: Petrophysical data of the natural sandstone samples.

Samples	ϕ	k_{gas}	k_{water}	V_{bulk}	V_{matrix}	$V_{pore(He)}$	$V_{pore(wet)}$	Injected quantity	
	(%)	(mD)	(mD)	(cm³)	(cm³)	(cm³)	(cm³)	Designed (ml)	Actual (ml)
1	32.86	1301	842	73.10	49.08	24.02	21.90	$V_{pore(wet)}$*1.00 = 21.90	22.00
2	33.12	1333	697	77.66	51.94	25.73	23.71	$V_{pore(wet)}$*0.75 = 17.78	18.00
3	30.95	1352	936	77.70	53.65	24.05	21.70	$V_{pore(wet)}$*0.50 = 10.85	11.10
4	32.70	1368	821	77.65	52.26	25.39	22.54	$V_{pore(wet)}$*0.25 = 5.64	5.80

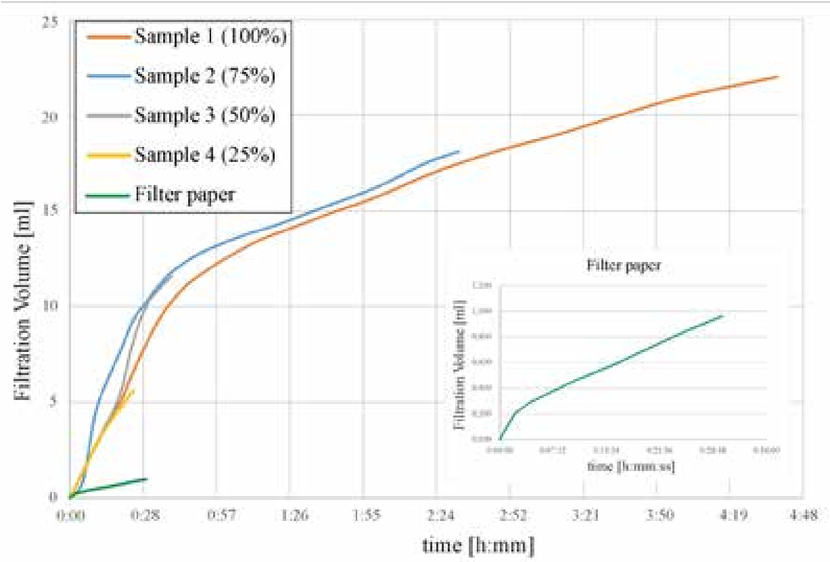

Figure 3: Comparison of filtration volumes of the examined core samples and filter paper at different equivalent filtration volumes.

should be noted that in the course of the previous examination (Varga *et al.*, 2018) with lower permeability values (24–165 mD) and LTLP conditions the filtration volume was clear from the beginning of the test. Accordingly, the test circumstances (higher T and P) and the larger pore throats connected to the higher permeability contributed to the appearance of the mud particles in the filtration volume.

There is a difference between the characteristics of the filter cakes produced by the standard test and the test with core plugs. On the surface of the filter paper a loose textured 1.2 mm thick filter cake formed. On the surface of the rock samples the thickness of the cake depends on the elapsed time. In the case of $V_{pore(wet)}$ = 25% equivalent filtration volume the filter cake does not even form; with increasing measuring time ($V_{pore(wet)}$ = 50%, 75%, 100% equivalent filtration volume) a two-layered filter cake developed. The upper layer (contacting the drilling fluid) is around 1 mm thick and is a loose textured, gelatinous material, while the lower layer (contacting the core sample) is a 4–6 mm thick, more consolidated, fabric-like textured material. This phenomenon was also observed by Mahmoud *et al.* (2018) with filtration testing on core samples.

Further information can be obtained by remeasuring the contaminated rock samples. As ***Figure 5*** shows, after the filtration test the core samples were re-measured by artificial formation water in the direction of the natural flow. As figure illustrates, the permeability deterioration is significant in the case of Sample 1. This is typical for the other samples as well; results are presented in ***Table 4*** in percentage form for each sample. According to the data, the permeability deterioration occurs to nearly the same degree in the cases of $V_{pore(wet)}$ = 25%, 50%, 75% and 100% equivalent filtration volume. This means that the first stage of the filtration process (spurt loss, without filter cake) is responsible for the permeability deterioration, namely the formation damage. Moreover, as the permeability remeasurement shows (***Figure 5***), the damage is not reversible by normal formation brine flow.

The results of the time dependence of the filtration process allow us to set up a proposal for the optimal filtration test protocol for measuring with core plugs. The permeability deterioration results show that it is sufficient to run the filtration test until the

Figure 4: The increasingly clean filtration volume of Sample 1.

$V_{pore(wet)}$ = 25% equivalent filtration volume. However, the filtration volume curve shows that in that case ($V_{pore(wet)}$ = 25%) the filter cake did not develop, while in the case of $V_{pore(wet)}$ = 50% it already exists and performs its task, blocking the flow of the drilling fluid. Taking into account these findings it is recommended to run the filtration test until the Vpore(wet) = 50% equivalent filtration volume is produced; the measuring time depends on the petrophysical properties of the rock core.

Summary and outlook

The newly invented measuring cell proved to be compatible with the OFITE 17-50-1 filtration test apparatus and works safely not just at LTLP conditions (Varga *et al.*, 2018) but at HTHP conditions as well.

As both previous (Varga *et al.* 2018) and recent measurements (***Figure 3***) show, the filtration volume curve can be divided into two sections, displaying the different parts

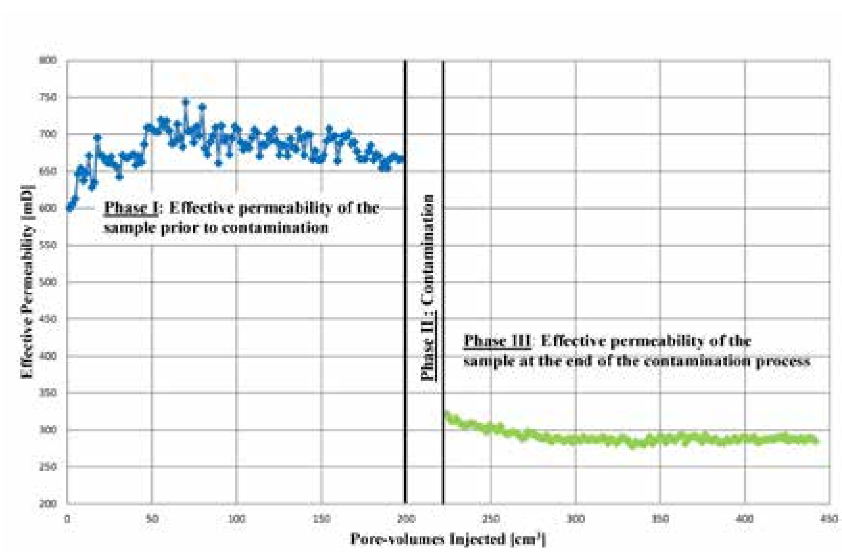

Figure 5: Effective permeability of Sample 1 before (phase I), during (Phase II) and after (Phase III) contamination.

Table 4: Petrophysical parameters of the core samples before and after contamination.

Sample	Porosity	Before contamination		After contamination	Decrease of permeability
		Abs. permeability	Eff. permeability	Eff. permeability	
	%	mD	mD	mD	%
1	32.86	1301	842	425	49.47
2	33.12	1333	697	274	58.11
3	30.95	1352	936	505	45.99
4	32.70	1368	821	366	55.42

of the filtration process (spurt loss, breakpoint, stabilised state). The most important difference is the filter cake development rate, which is much slower in the case of measurements made on core plugs compared to the conventional paper filters. It is important to note that this slower rate is closer to the process taking place at real bottom-hole conditions. Consequently, with this filtration test apparatus more realistic and useful information can be obtained about the behaviour of the drilling fluid in an open bore-hole section.

Our findings show that this method of measurement allowed us to determine not only filtration volume and filter cake properties but also the permeability degredation of the core plugs. Results show that even during the shortest measuring time ($V_{pore(wet)}$ = 25% equivalent filtration volume – 25 min) the permeability deterioration was equal to that present in the longest time frame ($V_{pore(wet)}$ = 100% equivalent filtration volume – 4 h 38 min) (***Table 4***). The formation damage to the core plugs was irreversible in all of the examined cases (***Figure 5***).

Taking all the results into consideration, it is recommended to run the filtration test on core plugs until the Vpore(wet) = 50% equivalent filtration volume is produced. For the recently selected sample group (porosity = 30.95 – 33.12 %, permeability = 697 mD–936 mD) the time required was around 40 minutes. The measuring time always depends on the petrophysical properties of the examined core plugs and should be determined for each rock core individually.

As this study is just one stage of an ongoing project, further investigations are planned. The main goal at this stage is the testing of the invented measurement method with different drilling fluids in static conditions, on rock samples derived from the same natural reservoir with similar petrophysical properties (for better comparison). At a further stage, tests using (water-based) drilling fluids containing nanoparticles will be the focus of interest. Finally, to reach the most realistic drilling/bore hole conditions a filtration test under dynamic and HTHP conditions is planned.

Acknowledgement

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EFG Strategic Plan 2018-2022

Towards a sustainable future

1. Developing and maintaining a strong EFG Member network

- To network for sharing knowledge, good practices and experience
- To disseminate policymaker agendas to National Associations (NAs)
- To facilitate information flow between Members and policymakers
- To represent geologists

2. Participation in the global community and maintaining international networks

- To participate in initiatives contributing to European policies on geosciences issues
- To enhance cooperation with international geoscience organisations
- To promote the global mobility of professional geologists

3. Promotion of geoscience professional excellence

- To promote the EurGeol title and uphold the status of professional titles
- To support the development and expansion of the Competent Person concept
- To promote Continuing Professional Development, supporting geoscientific education and high-quality training
- To promote professional specialisation and public access to registers of geoscience experts
- To support early career geoscientists
- To ensure monitoring of and strict disciplinary control over professional practice

4. Participation in EU and international funded projects

- To participate in funded projects to expand the network and EFG's capacity to influence policymakers
- To diversify income streams

5. Accessible communication of geosciences and outreach

- To create public awareness of the importance of geoscience to society by promoting public outreach and understanding of geosciences
- To communicate transparently to National Associations and other audiences

6. Provision of independent, reliable information on geoscientific issues

- To provide information to policymakers that is authoritative and objective
- To become the European organisation of reference on the professional practice of geoscience

EFG and EGU have established dialogue with policy makers on how the geosciences can help overcome Europe's major societal challenges

On 26 September 2018, the European Geosciences Union (EGU) and the European Federation of Geologists (EFG) jointly convened the *Horizon Geoscience: overcoming societal challenges, creating change* dinner debate. Held at the Royal Academy of Belgium, the event gathered nearly 80 policymakers from European institutions, media representatives, and geoscience professionals from different sectors and fields of expertise.

The dinner debate allowed researchers, policymakers and industry leaders to assess together how greater collaboration between these groups can help Europe overcome some of its biggest societal challenges. Encompassing a large number of scientific disciplines, the geosciences play a vital role in many policy decisions, including climate change, natural hazards, energy, mineral raw materials supply, space exploration, agriculture and ocean health.

Jean-Eric Paquet, Director-General at the European Commission's DG for Research & Innovation, concurred with the other high-level panellists that geoscience is central for public policy making and stressed the need for international collaboration, especially in the field of climate change and oceans.

The increase in international collaboration, as well as in multidisciplinary and cross-sectoral cooperation, have been highlighted by the geoscience community as the most positive outcomes of the European Union's Horizon 2020 Programme, which is allocating almost €80 billion to research and innovation over 7 years. In spring 2018, EGU and EFG jointly conducted a survey among geoscientists from across Europe, but also from abroad, to evaluate the perceived success of Horizon 2020. The Horizon Geoscience dinner debate offered the opportunity to launch a report outlining the survey's key findings and suggesting improvements to the forthcoming Horizon Europe framework programme. Although the participants were positive overall about the impact of Horizon 2020, the report also emphasised areas that survey respondents thought could be improved, such as the number of projects that focused on fundamental rather than applied research. Furthermore, the survey gave participants the opportunity to list areas they felt were underrepresented in Horizon 2020 projects. The areas most frequently listed were natural hazard management, hydrology and water resources, and raw materials and resources.

Jean-Eric Paquet then provided insights into the preparation for Horizon Europe, the ambitious €100 billion research and innovation programme to succeed Horizon 2020 in January 2021, which is currently under negotiation between the European Parliament and the Council. He emphasised especially the future support to mission-oriented funding, which will address the often-highlighted lack of continuity once projects officially end. Mr. Paquet also presented two key features of the forthcoming Horizon Europe programme: the European Innovation Council, which will enhance the commercialisation of innovative technologies developed by EU-funded projects, along with a multiannual strategic planning approach that will rely on initial consultations among the European institutions and strong engagement with citizens and civil society organisations at all stages. He finally underlined the importance of the budget foreseen for Horizon Europe and expressed his pleasure about the European Parliament's supportive attitude; it voted – by coincidence on 26 September 2018 – for an increase in the 2019 budget for research and innovation.

The second half of the evening involved round-table discussions over dinner, offering the opportunity for scientists, industry representatives and policymakers to come up with ways to reduce the barriers between the geosciences and policymaking.

In her closing speech, EFG Executive Director Isabel Fernández emphasised the event's relevance for the geoscience community, having succeeded in gathering more than 20 policy representatives from the European institutions. She also highlighted that the dinner debate was the first time that academia and industry representatives have joined forces to open a dialogue with policymakers on how geoscientists can support public policymaking more efficiently.

EAGE/EFG photo contest 2018

It has been an exciting run for this year's EAGE/EFG Photo Contest 'Geoscientists at Work', with 167 photos submitted and over 4,600 votes. The 12 finalists represent a range of countries and fields of activity, with highlights on young professionals and female geoscientists. The winning photo was taken by Ahmad Gholami in the Shahrud Desert, Semnan Province, Iran. Click here to discover all winners: ***https://prod.eage.org/en/photo-contest***

The 12 most popular photos have also been published in a desktop calendar for 2019 which you may order through the EAGE bookshop.

"Class in the desert" by Ahmad Gholami.

Horizon 2020 projects

Horizon 2020 is the biggest EU research and Innovation programme ever, with nearly €80 billion of funding available to secure Europe's global competitiveness in the period 2014–2020. EFG is currently involved in seven Horizon 2020 projects: ¡VAMOS!, UNEXMIN, CHPM2030, FORAM, INFACT, INTERMIN and MINLAND. Below you will find descriptions of the topics and aims of these projects.

¡VAMOS!

642477 - VAMOS
¡Viable and Alternative Mine Operating System!
START DATE: 1 February 2015
DURATION: 42 MONTHS
http://vamos-project.eu

The aim of the EU-funded ¡VAMOS! (Viable Alternative Mine Operating System) project is to design and build a robotic underwater mining prototype with associated launch and recovery equipment, which will be used to perform field tests at four EU mine sites.

EFG's role:

EFG supports the project through stakeholder engagement and dissemination activities.

The project has delivered an Innovative Mining System Prototype. In this context, EFG supported the selection of mining sites for field tests and the planning of field activities. For the future, the project has produced a feasibility, viability and market up-take. EFG contributed to the evaluation of the economic feasibility studies and to the Exploitation Plan for the VAMOS technology.

CHPM2030

654100 - CHPM
Combined Heat, Power and Metal extraction from ultra-deep ore bodies
START DATE: 1 January 2016
DURATION: 42 MONTHS
http://chpm2030.eu

The CHPM2030 project aims to develop a novel, pilot-level technology that combines geothermal resource development, minerals extraction and electro-metallurgy in a single interlinked process. In order to improve the economics of geothermal energy production, the project will investigate possible technologies for manipulating metal-bearing geological formations with high geothermal potential at a depth of 3–4 km in order to make the co-production of energy and metals possible; potentially this could be optimised according to market demands in the future. Led by the University of Miskolc (Hungary), the project is being implemented through the cooperation of 12 partners from 10 European countries.

EFG's role:

EFG supports the activities relating to the CHPM2030 methodology framework definition (WP1), particularly European data integration and evaluation: during the first months of the project, EFG's Linked Third Parties (LTP) collected publicly available data at a national level on deep drilling programmes, geophysical and geochemical explorations and any kind of geo-scientific data related to the potential deep metal enrichments. They also collected data on the national geothermal potential. Guidelines and templates for data collection were provided by EFG.

EFG also supported activities relating to road mapping and preparation for Pilots (WP6). EFG's Linked Third Parties assessed the geological data on suitable ore-bearing formations and geothermal projects collected in WP1, in relation with the potential application of the CHPM technology. This work combines these data with the outcomes of the most recent predictive metallogenic models. Only existing datasets will be utilised; no new surveys will be carried out.

EFG also leads the Work Package on dissemination.

EFG participated in the last Consortium Meeting from 4-7 September 2018 in Reykjavik, Iceland, to present its activities and exchange with the members of the Advisory Board during a tailored workshop.

UNEXMIN

690008 - UNEXMIN
Autonomous Underwater Explorer for Flooded Mines
START DATE: 1 February 2016
DURATION: 45 MONTHS
www.unexmin.eu

Thirteen organisations from seven countries across Europe are collaborating in this ambitious project to develop a submersible robotic system for surveying and exploring flooded mines. The €5 million project, funded by the European Union's Horizon 2020 research programme, will include the development of a Robotic Explorer (UX-1) for autonomous 3D mine mapping to gather valuable geological information that cannot be obtained in any other way; in general the mines are too deep and dangerous for access by human divers.

EFG's role:

Some of EFG's national associations participate in this project as Linked Third Parties and support the consortium through data collection for the inventory of flooded mines. EFG also supports the Work Package on dissemination and EFG's Third Parties disseminate the project results at national level in web portals, newsletters, conferences, workshops, educational activities, exhibitions or by any other relevant means.

As Work Package leader of WP5 (Stakeholder identification and engagement), EFG has recently focused on working on and coordinating the Task 5.1 Stakeholder identification and engagement and Task 5.4 Inventory of flooded mines.

Task 5.1 started at the beginning of the project and lasts until its end. Stakeholder identification and communication is essential to ensure the proper execution and success of the UNEXMIN project. The process will enable to maximise support as the project progresses. Therefore EFG has decided to review the stakeholder dataset that has been continuously created in collaboration with the Partners since the beginning of the project, in order to reorganise and complete it. EFG has also started to work on a stakeholders' engagement campaign.

Part of the UNEXMIN project was to create an inventory of flooded mines in Europe that will facilitate an online open-access user interface for browsing the database.

INFACT

776487 – INFACT
Innovative, Non-invasive and Fully Acceptable Exploration Technologies (INFACT)
START DATE: 1 November 2017
DURATION: 36 MONTHS
www.infactproject.eu

Exploration discovery of raw material resources requires innovations that change the geological targets of exploration, the physical places that are reached, or the manner in which they are explored. Despite its rich history of mining and residual mineral wealth, current conditions within the EU present a number of social, political, legislative, cost, technical and physical obstacles to raw material exploration: obstacles to be overcome by innovation, dialogue and reform.

The Innovative, Non-invasive and Fully Acceptable Exploration Technologies (INFACT) project unites stakeholders of Europe's future raw materials security in its consortium and activities. Via effective engagement of civil society, state, research and industry, the project will focus on each of these obstacles. It works to co-develop improved systems and innovative technologies that are more acceptable to society and invigorate and equip the exploration industry, unlocking unrealised potential in new and mature areas.

The project aims to develop innovative geophysical and remote sensing technologies (less invasive than classical exploration methods) that promise to penetrate new depths, reach new sensitivities and resolve new parameters.

The project will also set the EU on the world stage as a leader by establishing a permanent infrastructure to drive innovation in the next generation of exploration tools: tools that are cost-effective, designed for EU conditions and its raw materials strategy, and high performing in terms of environmental impact, social acceptability, and technical performance.

INFACT is comprised of the following main components:

- Development and testing of innovative, non-invasive exploration technologies.
- Foundation of three test sites for exploration technology in the south, centre and north of Europe.
- Stakeholder engagement, education and policy reform.

These actions combine to reach each of the main areas in which the EU has the power to influence change in its raw materials security.

EFG's role:

EFG leads the work package on dissemination and impact creation and several of the Federation's National Associations are actively involved in the project as Linked Third Parties.

FORAM

730127 – FORAM
Towards a World Forum on Raw Materials
START DATE: 1 November 2016
DURATION: 24 MONTHS
http://foramproject.net/

The project Towards a World Forum on Raw Materials (FORAM) focuses on developing and setting up an EU-based platform of international experts and stakeholders to advance the idea of a World Forum on Raw Materials and enhance the international cooperation on raw material policies and investments. This platform will work on making the current complex maze of existing raw material related initiatives more effective. As such, the FORAM project is the largest collaborative effort for raw materials strategy cooperation on a global level so far. Synergies with relevant EU Member State initiatives are being explored and fostered. Particularly, the project seeks to engage the participation of G20 member countries and other countries active in the mining and other raw materials sectors in order to share experiences and increase understanding of all aspects of trade in raw materials.

The FORAM project is coordinated by the World Resources Forum Association

(WRFA) and supported by eleven additional leading organisations (EuroGeoSurveys, European Federation of Geologists, United Nations University, Leiden University, University of Kassel, Clausthal University of Technology, ESM/Matsearch, Gondwana Empreendimentos e Consultorias, Servicio Geológico Colombiano, MinPol GmbH and La Palma Research Centre for Future Studies SL), which compose the FORAM consortium.

EFG's role:

EFG leads Work Package 3 on "Strategic Planning", which aims to set the stage for the World Forum on Raw Materials (WFRM) using a highly participative process. WP3 defines and presents a long-term vision and its strategic positioning, as well as an appropriate framework to measure performance and to respond to geo-political, technological and economic changes.

INTERMIN

776642 – INTERMIN
INTERNATIONAL NETWORK OF RAW MATERIALS TRAINING CENTRES
START DATE: 1 February 2018
DURATION: 36 months
http://interminproject.org/

INTERMIN will create a feasible, long-lasting international network of technical and vocational training centres for mineral raw materials professionals. Specific objectives:

- Develop common metrics and reference points for quality assurance and recognition of training;
- Develop a comprehensive competency model for employment across the primary and secondary raw materials sectors;
- Introduce an international qualification framework for technical and vocational training programmes;
- Create a conceptual framework for the development of joint educational training programmes based on present and future requirements by employers;
- Create and launch a joint international training programme by a merger of competences and scope of existing training programmes.

EFG's role:

EFG is cooperating with the project partners in six work packages, and acting as the leader in WP3 (Towards enhanced training programmes (Response)). The INTERMIN project aims at mapping, connecting and enhancing the existing European training and education initiatives in the raw material sector. Therefore, the INTERMIN consortium aims at creating a self-sustainable international network of specialised training centres for professionals from the raw materials sector, and BDG (Berufsverband Deutscher Geowissenschaftler e.V.) will participate in the INTERMIN project as a third party of EFG. The Polish Association of Minerals Asset Valuators (PAMAV) is also involved in the project as an EFG Linked Third Party.

EFG is supporting the communication activities, sharing relevant information about the project through its website, newsletters and social media accounts.

In WP1 International mapping of training programmes on raw materials and resources EFG has contributed to the definition of a skills catalogue used by the raw materials sector (D1.1). The INTERMIN survey on mineral raw materials training programmes (D1.2) (http://intermin.limequery.com/324595?lang=en) has been shared broadly within the EFG network.

Regarding WP2 Raw materials sector skills, gaps and emerging knowledge needs, EFG is contributing to the assessment of employers' needs and to the definition of skills gaps (D2.1).

MINLAND

776679 – MINLAND
Mineral resources in sustainable land-use planning
START DATE: 1 December 2017
DURATION: 24 MONTHS
http://minland.eu/

Access to mineral resources in Europe is one of the pillars of the Raw Materials Initiative (RMI). Yet competing societal interests, such as expanding cities, infrastructure development, agriculture and nature conservation, have had negative effects on the available area for exploration and mining of mineral resources. Consequently, the supply of mineral raw materials within the EU is at risk. Therefore, the integration of mineral resources policies into land-use planning at different scales and levels is a key factor for achieving the goals of the RMI.

The MinLand project is designed to address this challenge: to facilitate minerals and land-use policy making and to strengthen transparent land use practices. MinLand is composed around the acknowledgement that the call requires a broad and competent consortium with strong links to related projects and activities, a comprehensive and structured data repository, an efficient work flow and strong and broad stakeholder involvement.

EFG's role:

EFG supports the activities for valorisation and valuation of geological and societal data and civil society impacts. It is also involved in the network and clustering activities and in the communication, dissemination and exploitation of the project.

EFG is supporting communication activities by sharing relevant information about the project through its website, newsletters and social media accounts. Information about the MINLAND Delphi survey on "Future stakeholder needs and interests in mineral safeguarding and land use" (bit.ly/2yJPbJQ) has been shared broadly within the EFG network.

EFG is also producing a series of factsheets on the case studies analysed and studied within WP3. These factsheets will present a selection of relevant case studies in a visually attractive way.

In WP4 Land use practices, valorisation and valuation of geological and societal data and civil society impacts, EFG is contributing to the investigation of mineral policies and its requirements regarding land use in the EU Member states.

Submission of articles to European Geologist Journal

Notes for contributors

The Editorial Board of the European Geologist journal welcomes article proposals in line with the specific topic agreed on by the EFG Council. The call for articles is published twice a year in December and June along with the publication of the previous issue.
The European Geologist journal publishes feature articles covering all branches of geosciences. EGJ furthermore publishes book reviews, interviews carried out with geoscientists for the section 'Professional profiles' and news relevant to the geological profession. The articles are peer reviewed and also reviewed by a native English speaker.
All articles for publication in the journal should be submitted electronically to the EFG Office at ***info.efg@eurogeologists*** according to the following deadlines:

- Deadlines for submitting article proposals (title and content in a few sentences) to the EFG Office (***info.efg@eurogeologists.eu***) are respectively 15 July and 15 January. The proposals are then evaluated by the Editorial Board and notification is given shortly to successful contributors.
- Deadlines for receipt of full articles are 15 March and 15 September.

Formal requirements

Layout

- Title followed by the author(s) name(s), place of work and email address,
- Abstract in English, French and Spanish,
- Main text without figures,
- Acknowledgements (optional),
- References.

Abstract

- Translation of the abstracts to French and Spanish can be provided by EFG.
- The abstract should summarise the essential information provided by the article in not more than 120 words.
- It should be intelligible without reference to the article and should include information on scope and objectives of the work described, methodology, results obtained and conclusions.

Main text

- The main text should be no longer than 2500 words, provided in doc or docx format.
- Figures should be referred in the text in italic.
- Citation of references in the main text should be as follows: 'Vidas and Cooper (2009) calculated…' or 'Possible reservoirs include depleted oil and gas fields… (Holloway *et al.*, 2005)'. When reference is made to a work by three or more authors, the first name followed by '*et al.*' should be used.
- Please limit the use of footnotes and number them in the text via superscripts. Instead of using footnotes, it is preferable to suggest further reading.

Figure captions

- Figure captions should be sent in a separate doc or docx file.

References

- References should be listed alphabetically at the end of the manuscript and must be laid out in the following manner:
- Journal articles: Author surname, initial(s). Date of publication. Title of article. Journal name, Volume number. First page - last page.
- Books: Author surname, initial(s). Date of publication. Title. Place of publication.
- Measurements and units
- Measurements and units: Geoscientists use Système International (SI) units. If the measurement (for example, if it was taken in 1850) was not in SI, please convert it (in parentheses). If the industry standard is not SI, exceptions are permitted.

Illustrations

- Figures should be submitted as separate files in JPEG or TIFF format with at least 300dpi.
- Authors are invited to suggest optimum positions for figures and tables even though lay-out considerations may require some changes.

Correspondence

All correspondence regarding publication should be addressed to:
EFG Office
Rue Jenner 13, B-1000 Brussels, Belgium.
E-mail: ***info.efg@eurogeologists.eu***

Note

All information published in the journal remains the responsibility of individual contributors. The Editorial Board is not liable for any views or opinions expressed by these authors.

Subscription

Subscription to the journal:
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E-mail: ***info.efg@eurogeologists.eu***

Advertisements

EFG broadly disseminates geology-related information among geologists, geoscientific organisations and the private sector which is an important employer for our professional members, but also to the general public.

Our different communication tools are the:

- EFG website, ***www.eurogeologists.eu***
- GeoNews, a monthly newsletter with information relevant to the geosciences community.
- European Geologist, EFG's biannual journal. Since 2010, the European Geologist journal is published online and distributed electronically. Some copies are printed for our members associations and the EFG Office which distributes them to the EU Institutions and companies.

By means of these tools, EFG reaches approximately 50,000 European geologists as well as the international geology community.

With a view to improving the collaboration with companies, EFG proposes different advertisement options. For the individual prices of these different advertisement options please refer to the table.

Prices for advertisements

EGJ	**One Insertion**	**Two Insertions**
Full page (colour)	820 Euro	1320 Euro
Half page (colour)	420 Euro	670 Euro
Quarter page (colour)	220 Euro	350 Euro
Full page (black and white)	420 Euro	670 Euro
Half page (black and white)	220 Euro	350 Euro
Quarter page (black and white)	120 Euro	200 Euro
Business card size	90 Euro	150 Euro
Preferential location	25% plus	
Price for special pages:		
Outside back cover (colour)	1200 Euro	1900 Euro
Second page (colour)	1000 Euro	1600 Euro
Second last page (colour)	1000 Euro	1600 Euro
Geonews	**Annual Price**	
Ad and regular newsfeed	1500 Euro	
EFG Homepage		
Ad and regular newsfeed	1500 Euro	
University ad		
Ad for training opportunities in the job area of the homepage	500 Euro	
Annual package		
Business card size ad in EGJ, GeoNews and homepage.	3000 Euro	

FÉDÉRATION EUROPÉENNE DES GÉOLOGUES
EUROPEAN FEDERATION OF GEOLOGISTS
FEDERACIÓN EUROPEA DE GEÓLOGOS

EFG is the Voice of European Geologists

The European Federation of Geologists (EFG) is a not-for-profit professional organisation focused on the promotion of excellence in the application of geology and in raising public awareness on the importance of geosciences for the society. EFG is based in Brussels, was established in 1980 and includes today 26 national association members.

EFG adheres to the principles of professional responsibility and public service and certifies the competence, integrity and ethical conduct of professional geologists. Professional geologists, from the EFG national association members, contribute with their expertise in education, research and applied practice in industry and for governments in a wide range of activities that are vital to society and to protection of the public.

The EFG delivers its objectives through activities relating to:
• EU policies & environmental protection;
• Education & outreach;
• Free movement & professional titles;
• Professionalism & ethics;
• Supporting EFG Members.

EFG Members

UBLG - Belgium-Luxembourg
BGS - Bulgaria
CGS - Croatia
CAGME - Cyprus
CAEG - Czech Republic
GSD - Denmark
YKL - Finland
SGF - France
BDG - Germany
AGG - Greece
MFT - Hungary
IGI - Ireland
ANGI/CNG - Italy
KNGMG – Netherlands
Polish Association of Mineral Asset Valuators - Poland
APG - Portugal
NAEN - Russia
SGS - Serbia
SGD - Slovenia
ICOG - Spain
SN - Sweden
CHGEOL – Switzerland
TAEG - Turkey
UAG - Ukraine
GSL - United Kingdom

Associated members: AIG – Australia, CCPG – Canada, GSSA - South Africa and AIPG – USA

www.eurogeologists.eu