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Special topic - Electromagnetic Exploration
EMGS Gemini North prediction
PGS EM integrated solution
and EM HIGH RES techniques
Dear SPE The First reader,

The SPE Norway 2016/2017 Season is coming to its end. Filled with awards, surprises and wonderful moments, it has allowed us to learn, inspire and progress. The incredible Bergen One Day Seminar and Harstad Workshop in the Arctic proved one more time that they deserve to be listed as international SPE events, gathering many members and followers and giving valuable knowledge exchange. Technical nights, games, breakfast/lunch/dinner, social events like BBQ, sailing etc. are only a few of the various events that the SPE Norway offers us. We can be proud of SPE Norway programme. Do not miss the last event at your section this Season, before going on holidays!

Our young Magazine is celebrating its two years’ anniversary as SPE Norway regional publication, and three years since it was first launched by the Oslo section. Looking back at the history – we have grown a lot! It is incredible, after just two years we have been noticed: the SPE Presidents writing for us, having been mentioned at the annual main SPE conference (ATCE), articles from our members and SPE friends sharing their passion within the SPE Norway community.

As The First editors, we try to invite authors from abroad to share their ideas with our industry sector. We have published articles from authors from our neighboring countries, some of whom have even become our regular contributors, some from West and Middle East.

This issue is no exception! The Australian experience in the concepts of exploration chance of success predictions are shared with the Northern society. In addition, High Resolution Electromagnetic Exploration method and approach from neighboring Russia and from the local and leading EM marine companies are shared in this issue. If I may reserve of your time for one more thought. In the search for interesting ideas to share The First and looking for possible authors, I scan regularly updates in social media and in particular LinkedIn. Being a woman in the industry and having working experience from some of the harshest environments like working behind the Arctic Circle on the rig with outside temperatures -37 and wind 17 m/s, or in desert with +55C, I do appreciate seeing many events organized for women in the industry. Large oil & gas companies continuously post on LinkedIn and Facebook events like “Women in industry days”, or special events at conferences just for women, women recognition and awards. But! I cannot see anything being organized for men! Are there no men on the platforms? Do they not feel cold and tired? Do they not work in hard conditions?

Do they not work under stress? Do they not make discoveries? I believe men in our industry are not enough appreciated. Especially those born in the 90es, and making their careers in the interesting and fast-growing fields like biofields.

So, our dear men, we, professional women in the industry, would like to invite you to celebrate yourself and your great achievements! Let us organize events and reward on merit and not by gender. Like to invite you to celebrate yourself and your great achievements! Let us organize events and reward on merit and not by gender.

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Enjoy reading The First and as usual, do not forget to provide us feedback!

Vita Kalashnikova
QI Geophysicist, PAV-Geo AS

Maria Djomina
Communications Manager, AGR
WINNERS OF 2017 SPE REGIONAL AWARDS

For their outstanding contribution in the North Sea area at the regional level:

Jafar Fathi, Point Resources
Regional Service Award

Vegard Stenerud, Statoil
Regional Service Award

Jayantha Liyanage, University of Stavanger
Management and Information Award

Henning Dypvik, University of Oslo
Distinguished Achievement Award for Petroleum Engineering Faculty

4 awards to SPE Norway community—thank you for your engagement!

SPE’s regional awards are designed to recognize those members who have contributed exceptional service and leadership to the society, as well as those who’ve made major professional contributions to their technical disciplines at the regional level.

Dear Colleagues and Friends,

The whole oil and gas industry including Norwegian market has been adjusting for the past year and currently we probably see the price level which is acceptable for customers and country/companies - producers. Together we went through the revolutionary times of reshaping the future of oil and gas industry. Now we can clearly state that Our Industry is in a new era, era of completely new opportunities with more clear goals towards excellent technologies, improved efficiency, high safety standards and best professional. We collaborate closely with other high-tech industries as airspace, renewables and IT industry towards the bright and exiting future.

SPE Norway together with our five sections and our 4500 members and followers has been also challenged by new conditions. We experienced changing activity level, a reduction of members, cuts in funding and reduced participation in the major SPE Norway events including one of the best technical event such as Bergen One Day Seminar. However, it is a reminder for everyone that SPE is a unique platform established many decades ago and proven to be alive, adaptive and capable to serve for the best to the industry in good or difficult times. That fact motivated SPE to rethink the strategy how we can work and contribute to petroleum society in the new conditions and improve life for everyone. Therefore, we would like to state few corner points for future development:

- Standardization;
- Digitalization and Big Data;
- Broader skills and areas of expertise;
- Not just Networking but work better together.

**Standardization**

We work with the huge number of projects with big number of people and copious technologies on the market. Oil and gas is moving towards that to improve quality and reduce cost. Standardization is not making everyone the same, it makes the best to be selected to work at the right places.

In SPE Norway Council, we try to work more on having more standard approach to handle sections to get better-quality meetings and involve the best experiences from SPE International. We hope to get the best from each individual chapter and improve standards of the outputs, so at the moment we are running experience transfer between sections and you will see the new outcomes at your locations.

**Digitalization and Big Data Science**

More and more companies seek on improvements in digitalization and how to involve more big data science. Almost every major has a department to handle big data and improve performance of the companies and we see that frontiers are exceeding.

SPE Norway was one of the first focusing and organizing Big Data in Petroleum Industry and yearly Technical days in Oslo on the topic. We invite you to be active and improve your knowledge in that exciting topic for the next SPE meetings, check the agenda.

**Broaden skills and areas of expertise**

Tendancy from the last few decades was to narrow the expertise and to get specialized on special topics for professionals. Current two years lead toward new career path, towards wider areas and be a specialist in few topics as we’ve seen many guns in early time of oil and gas. That is exciting and never boring!

Let’s learns together and share knowledge, SPE courses and workshops are valuable addition to internal or external training and of course Distinguished Lectures. Our sections are very active to organise technical meetings and we aim to arrange internet streaming of the most interesting events and in addition of course The First Magazine publish high quality articles from local professionals.

**Not just Networking**

There is an area where Norwegian Petroleum business can improve and that is how to work better together and how to use networking. Norway is very different from North America Oil and Gas Market, where networking takes significant part of your time as an expert. From SPE Norway point of view, we focus to improve on networking and to make it fun and improve on knowledge transfer between professionals and towards students. This year we try to inform you more about events in the overall Norway to make our members who travels from parent location more aware about events in the different part of the country. Please look at the event schedule and drop by to one of the many interesting evenings in Norway, it available for every member.

We would like to encourage members to be active, go to the seminars, talk to each other, write articles, exchange knowledge, to do more and it will give you more energy back. Rethink the meaning of networking for you and use SPE venue for your best.

At the end, I personally would like to congratulate you with the upcoming summer days, that is time to be positive, get more energy and celebrate not only great weather, it is time to celebrate new opportunities.

Your sincerely,
Igor Orlov
SPE Norway Council Chairman

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The SPE President Jeneen Judah will visit Norway between 14-16 June (Oslo, Bergen, Stavanger).

Several events in each region will be arranged associated with her visit.

Please contact your section if you wish to attend.
The First SPE One Day Seminar in Bergen has already established itself as a strong tradition. SPE ODS brings high level technical presentations and latest research to Grieghallen, Bergen every year and facilitates meetings between international oil and gas community.

This year’s opening panel session had top management from Statoil, Faroe Petroleum and Wintershall Norway discussing possibilities to maximize recovery on the Norwegian Continental Shelf and the key factors as influencers. Despite downturn in the market, the attendance of international speakers, visitors and exhibitors proved once again that it’s crucial for the industry to focus on technological developments and best practice exchange. With over 200 participants, Statoil as a main sponsor and multiple service companies as exhibitors the event has met this year’s expectations.

And if you did not have a chance to visit SPE ODS this year we hope to see you in Bergen next year!

SPE Bergen Sailing with Statsraad Lehmkuhl

SPE Bergen Sailing with Statsraad Lehmkuhl is one of the most important industry networking events in Bergen and this year it took place on the 31st of May.

This year the event was kicked off with a presentation by Jim Kvamme from Wintershall: «Wintershall - Brage – Preparing for the future».

The annual sailing is always a sell-out, and participants including students enjoy a full evening at sea with excellent food, drinks and networking on, what many say, is Norway’s most beautiful ship.

With many students attending this is a great opportunity for companies to meet the most perspective graduates aiming for a career in oil and gas industry.

Is your company interested in attending next year’s sailing?

Contact SPE Bergen Section:
eirik.walle@spebergen.no

SPE Bergen TechNights

SPE Bergen Section organizes monthly TechNights for members of SPE and other Oil&Gas professionals. TechNights feature both, Distinguished Lecturer presentations, SPE papers and technology presentations. Our TechNights in Bergen gather around 50 participants from across the industry including students.

Do you have a SPE paper you would like to present at one of our TechNights? Has your company developed a groundbreaking technology or maybe performed a project with extraordinary results? SPE Bergen TechNights welcome presentation proposals from across the country.

For more information, contact: Jørn Opsahl
opsahl@tomax.no
Oslo Student Chapter

SPE Games by the Oslo Student Chapter

Finally, on Friday the 12th of May, it was once again time for the annual SPE Spring Games. This has become a strong tradition for the student members at UiO and something we look forward to every year. Big thanks go to the SPE Oslo Section for their financial support that made this year’s event possible.

The event started with three exciting presentations from Dr Reidar Mæhl. Prof Dag A. Karlsen and PhD candidate Arve Sleveland. Compared to previous years more technical themes, the focus this year was the state of the industry and the role of both professionals and students in the future. The presentations were both interesting and enjoyable and we thank all three presenters for their participating.

Barbeque, drinks and games followed. In great weather, six teams gave their all in various games, including sack race and potato spoon race. A well-deserved prize awaited the winning team. As always, the event ended with a party in the Geology building. All in all, the event was a great success and the work on getting sponsors for next year has already begun.

Company presentation by Lundin Norway

The SPE Oslo Student Chapter had the pleasure of hosting Lundin Norway at the University of Oslo on April 20th. Despite having a strong research cooperation with UiO, it was their first company presentation here. Begin one of the most successful companies on the Norwegian E&P market gave their all in various games, including sack race and potato spoon race. A well-deserved prize awaited the winning team. As always, the event ended with a party in the Geology building. All in all, the event was a great success and the work on getting sponsors for next year has already begun.

Time to celebrate!

SPE Norway

SPE Oslo Section

SPE Norway

SPE Oslo Section
There is much confusion in the conceptualisation and application of Chance of Success (COS) Predictions in oil and gas exploration. Although the basic statistical underpinnings of COS predictions are not mathematically complicated, in practice, there appear to be significant difficulties. The consequences of this in many cases include misplaced expectations and hence morale problems from results of exploration which fall outside expectations. In reality, commercial exploration success rates worldwide range from 30-40%. So, there is more pain than usual in our industry with the unfolding of expectations. As a result of this, companies have many times reacted in a knee jerk fashion to ‘correct’ their course which sometimes results in restructuring exploration teams and also changing the course of exploration. Much of the misunderstandings appear to arise from the fact that most small companies are involved in limited trials campaigns where budgets allow the drilling of only a handful of wells over 1-5 years. Realistic COS’ can only be based on expectations related to drilling a statistically significant large number of wells. In this article, the various probabilistic aspects of exploration expectations and outcomes are reviewed. Within the context of the intrinsic difficulty of not being able to guarantee any specific success, it will be shown how companies can choose the COS range inside which they should explore, to ensure survival and hence ensure sustainable growth over the longer term within chosen aggregate wells/ prospects drilled.

All the concepts and thoughts presented here are those of the author’s and do not necessarily represent the author’s employer Cue Energy’s views on this matter.

**Introduction**

What does a person making a probabilistic prediction actually mean? What does it mean to the person’s to whom this prediction is being conveyed? What are the impacts of the understanding/ misunderstanding between the probabilistic predictions made by the predictor and the person receiving these predictions? Having written on this subject, presented it many forums, and debated it, the author has found it to be a rather ‘slippery’ subject that has to be handled as tightly as possible. It is useful to discuss probabilistic predictions in a generic way first, then take it to probabilistic prediction of Geologic Chance of Success (GCOS) and then to Commercial Chance of Success (CCOS).

**Basic Probabilities**

A probabilistic prediction appears to have a real and at the same time unreal feel about it which might best be described by predicting the outcome of the throw of a six sided dice. For most people, the real part of the prediction would be the number put on the probability of a given outcome, say the number one on the dice, after one throw. That number which has a feeling of reality to it is 1/6 or 16.7%. The unreal component of such a prediction is that the predictor can never know exactly when that expected outcome number one will occur in reality.

Figure 1 shows the results of two experiments of throwing a 6 sided ‘fair’ dice 100 times. Success here has been defined as the outcome of a 1 and failure is defined as the outcome of the numbers 2-6. For each throw, the number of throws to that point n are noted and each time a success with the outcome of the number 1 occurs, a value of 1 is recorded for that nth throw. The remaining outcomes with numbers 2-6 are assigned values zero. At each throw, the cumulative success value, x, is updated to that point is also calculated. Thus at each point n, the average success rate up to that point is calculated by the formula x/n. The first set of throws in Blue shows a 100% success rate at the first throw because the first throw came in as a success with the number 1. In the second set of throws shown in Purple, the first throw did not deliver success, so it starts with a 0% success rate. Both graphs however converge towards the average value of 1/6 = 16.7% in the long run after the 100 throws, showing that for all intents and purposes, the dice is ‘fair’. However, note that long runs of no success can occur even in a simple dice. Especially note the purple graph where in success, more than 20 throws did not deliver the success number 1. And it is worth reiterating that this is the result with an obvious simple six sided ‘fair’ Dice. Exploration realities are much more complex.

**Presentation**

To illustrate a wider range of COS’ than a Dice can afford, the Microsoft Excel spreadsheet has been used to create Perfect Predictors for 10%, 20%, 30%, 40% and 50% COS’. At the heart of it is Excel’s random number generator function. Figures 2(a), 2(b) and 2(c) show the outcome of these COS computations. It is to be noted that the Excel random number generator does produce a ‘fair dice throw’ for all the COS’ because despite early oscillations, in the long run (Figure 2(a)), the COS’ converge to the predicted values. However, when we zoom into the first one hundred trials (Figure 2(b)), the ‘noise’ in prediction become clearer for smaller number of trials. In the early period, the COS’ crisis cross each other before starting to settle by the 100th trial. Figure 2(c) shows that within a window of the first 10 trials, there is a great deal of confusion between predicted and actual outcomes. And to think that all of this ‘confusion’ can occur in a ‘Perfect Predictor’. This is only one of many sets of 5,000 trials that one could attempt. In reality, all of such simulations will
the immediate area are carried out which will give an idea of presence, quantity, maturity, etc. of the source rocks, the presence and effectiveness of reservoir rocks, the presence and quality of sealing rocks. If more regional data is available, further analyses can be done including the evaluation of the presence/effectiveness of source and migration pathways, reservoirs and seal rocks etc.

Early lack of knowledge usually should lead to a more cautious, lower GCOS. At the Middle Stage, usually, reprocessing of seismic data with emphasis on structural, stratigraphic and possible seismic attributes is carried out. At this stage, the GCOS has the possibility of either going up or down from the initial GCOS but in this case the GCOS increases because the structural definition, especially of the fault improved and the ability to map the reservoir units more confidently increased with better seismic data. In the Mature Stage, 3D seismic data which is not necessarily a must in all prospects, was acquired specifically to enable further enhancement of structural/stratigraphic definition and also for seismic attributes that might help define reservoir and fluid content better. And in this case, structural, stratigraphic and fluid content understanding was improved with the 3D data.

The GCOS numbers offered, though fictitious, are not unrealistic in a real world setting. In fact, one of the valuable skills of seasoned G&G Evaluation professionals is the ability to predict what they can expect at the time of the next phase. The truth here is that an exploration well is more promising and GWAPs (G&G Analysis Professional) for GCOS will include the location of a discovery, discovery can be made commercial. Considerations would include the location of a discovery, discovery path to the Field Size Distribution, it is also tied to the MEPS. This is possible to work out the Minimum Economic Pool Size (MEPS) which would make a discovery commercial in that location. Based on the G&G team’s predicted field size distribution, it is possible to obtain the probability of finding a field at least the MEPS in the given prospect. The exact details of how all of this is done varies from company to company. It is presented in a simplified manner here for illustration purposes.

With this approach of going for a Commercial success in the first well, even an extraordinary exploration team can’t prove its capabilities in terms of finding hydrocarbons. Because the GCOS is not only about finding Commercial hydrocarbons. And more importantly, if a company plans to continue drilling in an area, the team will miss important petroleum systems information by not drilling optimally for this purpose. This has to be a calculated risk by the company. At the end of the day, it also ties the hands of the Explorationists in terms of limiting the crucial data that they have to gather for the longer term.

Exploration Realities and Challenges

Pre drill chance of success (CGOS) predictions appear to mean different things to different people. Although on the surface most professionals involved in oil and gas exploration seem to have an understanding of CGOS, when venturing deeper into what it actually means, there appears to be confusion both in the conceptualisation and the communication of meaning among others. It is the author’s observation, having worked with various teams within various organisations around the world that this confusion leads to ineffective approaches at exploration, inefficiencies in exploration execution, anxieties from the actual drilling team members, negative impact on team morale, and eventually loss of shareholder value.
SPE Norway – Exploration Success

The Prospect Field Size distribution histogram can be displayed in the form of the probabilistic prediction distribution below. Once the engineers/ economists have completed their studies, we get an idea of the Minimum Economic Pool size to make the project Commercial. From the cumulative distribution below, it is possible to obtain the probability that the MEPS reserve will be exceeded: %

By nature, Geoscientists like to believe that their methodologies are objective. However, at the end of all scientific analyses, a COS prediction is still subjective. Those who have worked in teams trying to obtain consensus on a COS would have an understanding of this. This subjectivity is also revealed by the different valuations that different teams’ companies make in block bids, though it is recognised that strategic considerations do have an overlay on this.

Once a COS is ‘finalised’ pre drill, say 30%, it is in some fascinating way that a negative drill result still takes everyone by surprise. This, despite the pre drill knowledge that on a single well basis the well has 70% chance of a negative outcome. There are real examples of high grade results, with a single drill result, that do not appear to have been understood.

Figure 7 shows the actual exploration success rates from a worldwide sample. It is sobering to note that worldwide our commercial success rates are a mere 18% in 1977 and 24% in 2017. The success rate of 24% in 2017 was given on a single well basis.

The results should be seen in aggregates. Figure 9 shows an alternative way to look at COS*. The line annotated as “The Survival Frontier” shows the number of wells required at any given COS for 90% certainty of at least one success.

Small to medium size companies typically have limited budgets over their 0.5-5 years corporate horizon. The ability to fund a given number of wells should guide where each company wants to play, to initially survive, then to grow. It is suggested that if funding is only available for 3 wells, then these companies should stick initially to wells with COS = 50%. Typically, lower risk would mean lower reserves. When the corporate budget increases, then materiality considerations may encourage a company to move “up the risk curve”. Note that at COS = 25%, you need 8* wells for 90% certainty of at least one success. It is important also to note that the 3 or 8 wells referred here does not mean sequential drilling, regardless of outcome of any given well. If any well result downscales any future prospect, then it is suggested that the company drills the next alternative acceptable COS prospect which may take some time to firm up in the same play or elsewhere.

Although risk, costs and rewards must be considered, the assumption made here is that survival is of utmost importance for small companies, while building up materiality. Any form of comparing prospects on risk weighting or on the basis of EMVs is not discussed here because ‘expectations’ are only achieved after a statistically significant number of wells are drilled. It is implicitly assumed here that all wells drilled will make enough money to cover all costs, i.e. the wells are all of positive NPV in the success case.

Conclusion

There exists a great deal of confusion on the conceptualisation, communication and interpretation of Chance of Success predictions in our exploration business. These challenges are non trivial and do affect the efficiency and effectiveness of the exploration effort to various degrees in different companies. Given the probabilistic nature of our business, it is desirable to have the greatest clarity in what we mean by our predictions and how we operate within this realm of uncertainty. The better the flow of understanding at all levels, the less the losses, and more the gains from our exploration effort for the money expended.

In summary, with a broader perspective of looking at exploration as an aggregate effort rather than a well by well effort, a more efficient and effective exploration program can be laid out and executed, thereby increasing shareholder wealth at the same time as keeping company morale intact.

Acknowledgement


There are many who have contributed to this paper via discussions and peer review and I acknowledge my paper. However, I take full responsibility for the contents of this paper.

Figure 1 - This graph is from my consulting days in India where in trying to convey these concepts, I enlisted the assistance of our then young daughters Priya and Sharmini, who in a Mumbai Hotel assisted me with throwing Rupa coins and Dice when I was writing the early part of this paper in the mid 2000’s. I remain indebted to them for assisting in this experiment.

This paper also includes many of the concepts developed by the author in LinkedIn articles since December 2016.

* COS = 25%, Chance of back to back failures drilling 8 wells = (1-25%)^8 = 10%. Therefore, the Probability of at least one success after drilling 8 wells is 90%. You could choose to drill higher COS numbers as 50% COS where the 90% chance of at least one success is delivered with 2 wells.

About the author

Bala Kunjan has 40 years G&G experience in exploration and development across the Oil and Gas industry in Asia-Pacific Basin of Malaysia, Indonesia, India, Australia, New Zealand, and the USA. He has worked within integrated teams of geologist, geophysicist, and reservoir engineers, leading to significant field developments and discoveries such as the Barua Oil Field (India), Krishna Godavari Basin (East Coast India) Deepwater Discoveries, East Spar Gas/Condensate Field (Carnarvon Basin, Australia), Tut Oil Field (Taranaki Basin, New Zealand), Canton (Hong)/Netherby Gas Fields (Olwyn Basin), Yolla Gas/Condensate Field (Bass Strait), many Cooper Basin Gas and Oil Fields and the Oyong and Worrol oil and gas fields in the Madura Straits, Indonesia. He has been noted for mentoring younger geoscientists since 2004. His core areas of interest is in mentoring/communicating exploration risk and planning for sustainable long-term success through anticipated probabilistic outcomes from given asset portfolios. He has a BSc Hon in Geophysics from the Science University of Malaysia, Penang, 1977 and an MBA from the Australian Graduate School of Management (AGSM), University of New South Wales, Australia, 1990.

Having started his career with Enco in Malaysia (1977-1985), he has worked as an in-house/consultant with various companies including Delhi Petroleum (Adelaide), Santos (Adelaide), Western Mining (Perth), Command Petroleum/ Cairn India (Sydney/Adelaide/Chennai), Reliance Industries Limited (Mumbai), AWE (Sydney) and Drilsearch (Sydney). Currently he works with Cue Energy in Melbourne. Bala is a member of the ASEG Visiting Fellowship.
Ivar Aasen’s start-up is a huge milestone for Aker BP. As operator, the company has completed the development in a challenging period for the industry. It is therefore particularly satisfying that the project was delivered within total budget and on schedule.

Around 17 million working hours were invested in the project and there were no serious HSE incidents. This means that the project has satisfied the four main goals:
- no serious incidents
- a high-quality delivery
- delivery on time
- within budget.

Drilling operations on Ivar Aasen have been world-class in terms of the speed of the drilling, its high quality and good safety. Statistics from Rushmore confirm this (Pic 1). The excellent progress on drilling operations has so far contributed close to NOK 2 billion in savings for the project. This has been an important factor in the completion of the project within the total budget. The drilling has taken place in close cooperation with the Department of Petroleum Technology and the Department of Drilling and Well Operations, along with Maersk Drilling, Schlumberger and other service companies.

The wells on Ivar Aasen are drilled using geo steering. Maersk Interceptor’s every move on the Ivar Aasen field is closely monitored from a dedicated office in Trondheim – two kilometres into the ground and two kilometres horizontally through shale, conglomerates and, preferably, oil-bearing porous sandstone. The sandstone’s density and resistance are being measured. The information is checked against the seismic data and interpreted on a continuous basis. There are darcy and net gross, sections and faults. The changes cannot be too sudden, as sand screens must be installed that are not very flexible: Should we drill straight forward, should we go up or down? The cost of every hour runs into millions, but if things are done correctly, hundreds of millions can be saved or made. It is like guessing the next card in a deck – up or down. Tor-Ole Jøssund was responsible for ensuring that the decisions made are the right ones: ‘It's like driving a car while only looking through the rear-view mirror. The information we receive from the drill bit is often one hour behind – we are always about 30 metres behind. This means that we have to make choices that in hindsight may prove to be wrong. You do not get the full picture until the next day. That is the nature of geo-steering. Ivar Aasen is as just uncertain and complicated as we had envisioned. It will not be plain sailing to produce the oil from this field – but we will manage. The management has told us to lead the way in Petro on the Aasen field. What we do here is world-class; I do not know of anyone else doing the same as us. Here we make important decisions 24 hours a day, 7 days a week – including on public holidays.’ ‘The Petek team cooperates very well with the drilling team. They are efficient and do an excellent job. We are one excellent team. I’m really proud of what we’ve achieved together.’

Probably the best

“We shouldn’t really say it out loud, but we’ve probably set a world record in drilling on Ivar Aasen.” Nonetheless, Odd Inge Sørheim is proud of having drilled 246 metres on Ivar Aasen in one day. Now the goal is to be even better.

We are in the control room for the drilling team in the Funka’s building in Trondheim. Drilling Superintendent on Ivar Aasen Maersk Interceptor, Odd Inge Sørheim shows graphs that he believe says it all. A total of 246 metres of drilling progress per day for D-19 and an average of 201 per day for all the six wells combined. The average on the Norwegian continental shelf is about 100 metres: ‘The figures don’t lie; they show that we’re twice as good as the average. That’s not bad, but we could do even better.’ When it comes to completion of the drilling holes, so that they can produce the oil, the results are perhaps even more impressive. It took 9 days on average on Aasen, compared with an average of 21 days on the Norwegian continental shelf. There is certainly nothing ordinary about it. Maersk Interceptor has completed 528 metres a day, while the average on the continental shelf is 234 metres. ‘There’s no doubt that we’re the best – by far. I’m sure our completion speed constitutes a world record.’ ‘Of course, we have a great rig with an excellent crew, but do the others – without achieving results like these. The success is because we have chosen to work as an integrated team together with Schlumberger, TechnipFMC and Maersk. We all work together and quickly deal with problems as they arise.’
Removing solids from well flow using dynamic desander technology boosts production and simplifies interventions

by Dmitri Gorski, Senior Process Engineer, BRI Cleanup

Sand and other solids are present in the production flow of most of the producing wells today. Statoil highlighted the value of dealing with solids production topside instead of using expensive well completions more than 10 years ago (Andrews et al., 2005). In this SPE paper, the StatOil engineers reported that the use of sand control completions was minimized when developing in the StatFjord and Gullfaks fields. This strategy was described as a success. Not only the predicted significant gain in production acceleration could be realized, but also an increase in reserves (IOR) could be demonstrated. The authors did not propose any methods for separation and disposal of sand topside upon the utilization of the above described production strategy. Back then, few options for dealing with produced sand topside were available. The approach was rather to establish a Maximum Acceptable Sand Rate (MASR) value based on the capacity of the process system on-board to deal with the incoming sand. This paper suggests a way of significantly increasing the MASR value using novel technology for continuous removal of sand from the well flow topside. The technology is based on hydrocyclone separation, enhanced using a motor-powered impeller. The method has been extensively tested in Norway and abroad during the past 14 years.

Most of us know how much damage produced solids can do to the topside facilities. Sand-blasting of piping systems and various down-stream equipment will soon enough lead to erosion damage. In worst case, this can result in loss of containment and hydrocarbons on deck. Sand and solids also tend to plug process systems, leading to a need of cleanouts. A common example of this is production separators, where a lot of sand accumulate if not taken care of upstream. In the case of separators, there are now online jetting systems which help flush the sand out. However, this does not eliminate the risk of erosion upstream, and the jetting does lead to production disturbances.

Hydrocyclones are traditionally used for in-line separation of solids from liquids. A hydrocyclone is a simple equipment that has been in use, virtually without modifications, since the end of the 19th century. Today, hydrocyclones are used everywhere: from the automotive industry and mining to home appliances. The principle of operation is simple: an orifice at the inlet of the hydrocyclone increases the velocity of the fluid flow to a point where sufficient centrifugal force is created in the hydrocyclone vessel to force most of the solids particles to the walls. There the particles sink to the bottom, where they are discharged. The “clean” liquid overflow contains significantly less solids and can be sent to the next processing stage. High fluid velocity is detrimental for the performance of the conventional hydrocyclone. Any separation process requires energy, and in a conventional hydrocyclone, where inlet flow is subject to large variations, will be just as unstable.

At the same time, it is becoming more and more clear that significant savings can be made by integrating a desanding hydrocyclone into a topside processing facility. A lot of trials, where hydrocyclones have been used for inline cleaning of process stream from solids, have been carried out over the past 15-20 years. The first wellhead desander was deployed in 1996 on the Shell Brent field in UK, and since then there have been several installations worldwide (Rawlings; 2014). Trials with a bulk desander on Gullfaks C platform on the Norwegian shelf showed savings of at least 20 million NOK due to reduced need for well interventions alone (FourPhase; 2016). Numbers from multiple wellhead desander installations in Asia are not officially available, but a significant increase in production can be assumed there. However, most of the conventional hydrocyclones that exist on the market today are bulky, manually operated, and lack automation and integrated monitoring of separated solids (Hallbutton; 2017, Schumberger, 2017; eProcess; 2017). Additional washing systems are often required to remove oil rests from the separated sand. Some of the existing conventional hydrocyclones are more compact than others, and some are equipped with a certain degree of automation and monitoring (FourPhase; 2015). Yet none of the conventional hydrocyclones employ a separation principle that is significantly different compared to hydrocyclones of the late 19th century. The need to improve shortcomings of conventional hydrocyclones to overcome their disadvantages has been there for some time.

Finding a way to decouple the energy driving the separation of solids from the energy of the well stream would vastly improve the fundamental working principles of a hydrocyclone. If this is achieved, the separation process would no longer be as unstable due to instabilities of the well flow. A possibility of providing additional energy to the separation process would also open up, thus making the separation potentially more efficient and controllable. Finally, dependence on the unstable inlet nozzles, and the need of protective liners, might be eliminated. The first idea of how to achieve all this formed in the late 1990s in Norway. Experiments where an impeller, powered by an electric motor, was inserted into a hydrocyclone vessel led to the development of the first dynamic hydrocyclone. Further research into this concept elsewhere firmly defined the term “dynamic hydrocyclone” as describing motor-powered impeller in a hydrocyclone vessel (Jiao et al., 2006, Zhou et al., 2014). This approach represented first principal improvement of the hydrocyclone separation principle in more than a century. The patent granted for dynamic hydrocyclone technology was sold several times, and is now owned by BRI Cleanup, a small Norwegian company located in Aalesund outside of Ber-
A unique characteristic of DDS™ is its ability to clean the sand while it is separated and discharged. No additional cleaning equipment is normally required, which simplifies the disposal of the sand if brought to shore. In some parts of the world, where it is permitted to discharge the sand overboard, the sand even meets the strict authority cleanliness standard without the need for additional treatment. When a conventional hydrocyclone is utilized, there is often a need to install subsequent filter equipment is most often not required when DDS™ is employed and removal of particles with sizes down to 5 microns has been recorded.

Deployment of the Dynamic Desander System™ on an offshore platform in Malaysia led to doubling of production for some of the connected wells. In Norway, the system is often in use on well interventions and flow-back operations. Integrated into a coiled tubing (CT) package, the DDS™ gives coiled tubing operators real-time information about the amount of solids coming from the well. It also prevents any solids in the returns from entering coiled tubing fluid circulation or platform processing systems. Recently, dynamic hydrocyclones made an appearance on the US market, where efficient dealing with the return of solids has been an unresolved issue for unconventional fracking operations. A unique capability of the DDS™ is to handle variations in flow and large amounts of gas, while simultaneously maintaining high separation efficiency due to dual separation action proved to be detrimental for its success. Based on the proven track record of the DDS™ technology, its compact size and the potential for automated continuous operation, it could be suggested that there finally is a permanent solution to the topside solids issue. Benefits described by Statoil engineers back in 2005 can finally be realized.

Figure 4. BRI Cleanup Dynamic Desander unit in unconventional fracking operation in USA.

References

Figure 2. Brand of Dynamic Desander System™, see technology over conventional hydrocyclones include:

Two-stage separation in one vessel (hydrocyclonic separation is enhanced with centrifugal action of the impeller), which guarantees superior performance independent of the flow. No need for inlet nozzles and liners, which significantly improves HSE aspects as well as leading to better operational characteristics. No pressure drop (and in fact an increase in pressure as illustrated in Figure 3). Dynamic Desander System units are highly automated and provide real-time data on the weight of separated solids and other process parameters. They are fully integratable into platform systems. Each unit consists of upper separation vessel and lower accumulator vessel. The sand, separated in the upper vessel, sinks into the lower vessel, which can be discharged to a recipient of choice (e.g. sand skid or rig’s cutting re-injection system). The separation process is continuous and does not stop even during the sand discharge sequence, which only takes a few minutes. Another unique characteristic of DDS™ is its ability to clean the sand while it is separated and discharged. No additional cleaning equipment is normally required, which simplifies the disposal of the sand if brought to shore. In some parts of the world, where it is permitted to discharge the sand overboard, the sand even meets the strict authority cleanliness standard without the need for additional treatment. When a conventional hydrocyclone is utilized, there is often a need to install subsequent filter equipment is most often not required when DDS™ is employed and removal of particles with sizes down to 5 microns has been recorded.

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SPE Norway – Well Flow

WELL CLEAN OUT AFTER REPERFORATION 98% SEPARATION EFFICIENCY

Shell Gannet, North Sea

Solution
There was a high expectation of sand during the initial cleanup, therefore the use of the FourPhase DualFlow solids removal system was chosen for the collection of any sand produced to surface assuring high separation efficiency and minimal space requirements due to system’s compact design. The FourPhase system continuously separated and removed solids which were then flushed to external skips on the hatch deck. The cleaned return fluids were routed to an unused wellhead to allow access back into the production stream.

Result
– No recorded HSE incidents.
– No recorded equipment downtime.
– 912 kg of solids separated during the cleanout operation.

Challenge
Two wells were planned for cleanup flow after reperforation using wireline intervention. The aim of performing the cleanup was to enhance production from the wells post reperforating. Once the FourPhase solids removal system was mobilized, the scope of the operation was expanded by two additional wells.

Operational considerations:
– High expectation of sand during the initial cleanup.

Test provided by Giedre Malinauskaite
Marketing Manager, FourPhase

Figure 4. BRI Cleanup Dynamic Desander unit in unconventional fracking operation in USA.
In 1965 Gordon Moore, one of the Intel co-founders, predicted that the number of transistors in a dense integrated circuit doubles approximately every two years. This is known as Moore’s law and the statement has proved to be true over the last 40+ years. These days we have technology that grows even faster than the CPU’s – graphical processing units (GPU).

Recently, new generation of GPU became available for general purpose computing with the support of double precision floating point operations, necessary for dynamic reservoir simulations. The graphics cards currently available on the market have thousands of computational cores that can be efficiently utilized for high-performance simulations, Figure 1.

In addition to the number of cores, the latest GPU’s also have significantly greater memory bandwidth, which is equally important for efficient parallel simulations as it is effectively the speed of communication between the cores. The progress in this component is so rapid that we can expect further breakthroughs in this direction and significant changes in the hardware world in the nearest future.

The software development team in Rock Flow Dynamics has recently implemented capabilities to run simulations in hybrid CPU-GPU mode, utilizing all computational power available. The hybrid parallelization algorithms distribute the workload between CPU and GPU hardware components so that all computer resources are utilized for the best simulation performance.

The results have shown that utilizing of combination of CPU and GPU in the simulations, balancing the workload between them, significantly improves the simulation time. For example, let us consider the well known SPE10 case, which is often used as a benchmark for simulation performance. The model is strongly heterogeneous and has large differences in the reservoir properties, which is always quite a challenge for the simulation software. The figure 2 shows comparison of the simulation time on 3 various platforms: regular laptop, CPU, and hybrid CPU-GPU, showing the advantage of utilizing all available power.
with 4-cores CPU, powerful dual-CPU workstation (somewhat like HP z840) and the laptop from the first test but with GPU enabled for computations. As you can see form the figures, the difference in the simulation time between the cases with and without GPU is 5-6 times. The simulation time is reduced significantly, without too much investment in hardware. You can find a laptop of this kind in any hardware shop for about $2000. It is also worth mentioning that a machine like this outperforms a significantly more expensive workstation with 40 CPU cores (~$15000) by about 2 times. It is actually quite difficult to predict where the hardware competition is going to go in the near future. Even before the end of this year we can expect several releases of the new chips by Intel, NVidia and AMD. Time will tell who is going to deliver the best results, but there is no doubt that the high-performance hardware world is changing rapidly these days and we can expect reservoir simulations to run significantly faster in the near future. The race is definitely going to be interesting...

Comparison of the simulation time on 10 random real-field 3-phase black-oil models.

Figure 2. SPE 10 benchmark for simulation time. 4-cores laptop – dark blue line; Dual-CPU workstation – light blue line; 4-cores laptop with GPU – red line.
Cased Hole Reservoir Layer Pressure

by Remke Ellis and Rita-Michel Greiss, TGT Oilfield Services

One of the most critical measurements for reservoir management is that of formation layer pressure. Various methods are employed to determine reservoir pressure however many techniques only measure average reservoir pressure and should not be used for multi-zone reservoirs that are differentially depleted. Multi-rate PLT method is used to measure formation pressure across individual perforation intervals, but the assumptions that all fluid exiting a perforation interval is confined to a particular unit (i.e. there is no fluid redistribution behind pipe) and uncertainties in unit thickness can result in significant errors. Triple Rate Spectral Noise Log method (TSNL) measures the pressure for each active layer independently, regardless of behind pipe fluid redistribution. TSNL, is based on the same hydraulic diffusivity equations as multi-rate PLT method but uses reservoir flow Noise Powers (NP) instead of transmission flow rates (Q). This means that flowing reservoir units are evaluated independently even when fluid from multiple layers commingling to the same perforation intervals. Furthermore, SNL directly measures effective formation (flowing) thicknesses behind pipe, which is an important input for the technique and also enables assessment of reservoir performance and helps refine estimation of reserves. The SNL-HD panel shows noise data in three dimensions: Depth, Frequency and Amplitude. Figure 1 illustrates noise acquired by SNL-HD for different fluid movement pathways. Displaying the SNL-HD data like this means that the noise associated with individual unit reservoir flow can be distinguished from that associated with the commingled borehole and cement channeling noise, allowing for each layer to be assessed independently. The intensity of the noise amplitude is directly proportional to the product of flow rate and differential pressure. These relationships determine frequency and intensity form the basis of TSNL technique.

TSN1 Concept of Measurement

This technique uses hydraulic diffusivity equations in conjunction with SNL noise power ratios in order to determine external boundary pressure of reservoir zones under flowing conditions. McKinley pioneered the first laboratory studies investigating the relationship between energy dissipated by fluid flow through a media (equivalent to the product of flow rate and pressure differential) and the strength of associated acoustic signal generated (noise power). Figure 2 presents McKinley’s results, revealing a linear though scattered relationship. The scattered distribution of McKinley’s data is linked to limitations of the equipment used at the time. Noise power (NP) represents a fraction of kinetic energy that is lost from the system as noise, so it is not surprising that it varies linearly with system enthalpy. Little or no research work has been done since the McKinley experiments, until 2012 when the implications of what the study revealed were realised. 

Proportionality of NP with energy dissipation (Q.dP) allows for the substitution of Q with NP in hydraulic diffusivity equations (see SPE 177620). This means that a producing / injecting well can be kept on line, and simply by varying the flow rates one can determine pressure of flowing units. Unlike PTA with downhole gauges or multi-rate PLT method, TSNL records NP specific to discrete flow units, and can therefore determine individual layer pressures, even behind pipe.

Examples in Silicaceous Deltic Environment - SPE 177620 - MS

Spectral Noise Logging technique has been utilized to estimate the average reservoir pressure for each perforated layer in a multi-zone single completion oil producer. The noise logging survey has been carried out under flowing conditions with 3 different rates (see figure 3).

The main conclusions were as follows:

1. The pressures estimated by the TSNL technique without shutting-in the well were in good agreement with the Open Hole Formation Testers. Additionally SNL determined the effective flow thicknesses of all layers, identified the source of produced water and also resulted in tested intervals un窦ted by RFT.
2. The technology does not require shutting in the well, although it requires stable flow at conditions above fluid saturation point (single phase).
3. This technology is particularly suited for when target zone is behind a string, such as in dual string well completions.
New technology often comes at a premium. Development and marketing costs, upgrades to manufacturing infrastructure and the overall hype surrounding a new product entering the market usually translates into a price uplift for end-users. Improved data quality, along with increased safety and efficiency, can sometimes rationalize the extra costs. However during an industry downturn these justifications are less likely to be accepted, motivating service providers to become more creative with technology that is already available in order to surpass project objectives.

**XArray** is one example of such innovation which, through harmonious integration of currently available technologies, provides a tailored solution to survey design. The result is increased efficiency of up to 50% along with significant improvement in data quality. As it uses technology that is already available and deployed in the fleet, it comes with no additional capital outlay, HSE exposure, or cost uplift to clients. This improved efficiency and data quality derives from leveraging dense shotpoint intervals and multiple sources to improve croseline sampling.

In towed streamer configurations, inline sampling is calculated by halving the distance between receiver groups on the streamer. The industry standard streamer receiver group intervals of 12.5m achieves an inline bin dimension of 6.25m. Croseline sampling on the other hand is the result of the streamer interval divided by twice the number of sources used. In the case of dual source acquisition, the croseline bin dimension is one quarter the streamer interval. In the case of XArray, croseline sampling is one sixth when three (Triple) sources are deployed and one tenth for five (Penta) sources, resulting in a considerable increase in croseline (CMP) sampling while using the same amount of in-sea equipment.

Several benefits become evident from this initiative. Apart from the resolution uplift that is achieved leading to enhanced imaging, XArray Triple works without restriction to spread width so high quality data can be acquired without increased acquisition time. Additionally with square bins at 6.25 x 6.25m, in the case of XArray Penta, it is no longer necessary to define line heading by the predominant direction of structural dip since sampling is equal in both inline and croseline directions. The survey azimuth can be chosen to maximize operational efficiency, adapting to survey geometry and operational restrictions. We have seen several cases where the survey economies are drastically improved, sometimes making the difference between a viable survey and not shooting at all.

Shot de-blending is the most cutting edge of all the elements of XArray. Blended marine seismic acquisition emerged in the late-1990s and allowed shot interference (by means of continuous recording). However the blended data obviously needed to be separated in processing and the attempts to de-blend effectively have come in various flavors over the last ten years, driven by the general consensus that it will be an integral part of seismic acquisition. Recent technological advancements have made the process become a practical routine.

XArray uses what is more accurately referred to as ‘near simultaneous shooting’ (Berkhout et al, 2008) where shots are fired in distance mode according to a dense pre-plot of regularly spaced shotpoints. Although shot locations are regularly spaced in distance, there is a natural randomization in shot times that results from small variations in the time it takes a vessel to travel from one shotpoint to the next. This natural randomization of firing time is exploited to allow for effective separation in the de-blending process.

Combining the use of continuous recording technology, dense inline shotpoint intervals and multiple sources, Polarcus has leveraged survey design and de-blending in processing to provide tailor-made seismic solutions under the banner of XArray. The component technologies are well accepted in the industry and utilize equipment currently available onboard our vessels and familiar to our crews. The flexibility gained by the XArray method allows for reduced turnaround time from first shotpoint to drilling, reduced HSE exposure and improved data quality. Polarcus has acquired over 40,000 km² of dense shotpoint and XArray data to date, and there remains growing interest in applying the method in basins around the world.
Introduction to EM techniques

EM for Hydrocarbons Exploration

Electromagnetic (EM) methods are well known in implementation for geological structure investigation (from 1910) and ore exploration (1920s). First methods for hydrocarbons exploration were carried out in 1928-29. The first use of marine electrical prospecting for oil and gas exploration dates back to the early 20th century (Schlumberger, Schlumberger and LeSaulnier, 1934). In the 1970s and the late 1980s the 20th century are the turning points in the development of marine methods of electro gas exploration [1]. In the late 1970s, the US military had to release the resistance of the oceanic lithosphere to quiate radio communications with submarines. The development of a sounding technology, known as Controlled-Source Electromagnetic (CSEM) method [2] began with the financial support of the military departments at the Scripps Oceanographic Institute in the United States. This method had a huge impact on marine EM exploration. Until the late 1980s, studies of the EM properties of the lithosphere, carried out by western academic researchers in the framework of scientific projects. In the 1980s, Exxon explored possibilities of EM exploration for hydrocarbons detection (US Pat. No. 4,617,518 A, 1986). The beginning of mass commercial application of the method was related to the end of the 1990s, when oil companies began investing money in the development of the theory, equipment and methodology of CSEM due to high hydrocarbon prices and the start of deep sea drilling in the Gulf of Mexico. Since that time, the industrial application of electrical exploration in the oil and gas industry begins, and CSEM became the leading electro-prospecting method. After the global EM crisis, which began with the financial support of the military departments at the US military, the method has been developed rapidly, with many companies and research groups around the world. The present study reviews the most practical CSEM properties and the method and configuration do not really matter for impact the results. The solution of the direct problem is unique, but this is not unique for inverse problem which is ill-posed. Solutions can be found by solving the system of Maxwell's equations numerically.

EM source current waveform, and consequently frequency response and the EM crisis, which is depended on resistivity (ρ), magnetic permeability (µ), and the density of conduction current, and ρ is the electric charge density. In addition, solving a direct problem of geoelectricity is to find the parameters of the object using a given field. The source of those fields is caused by natural electrochemical activities or polarization in the media and is depend on resistivity (ρ) in the Earth.

Acquisition can be conducted onshore, offshore, air, mines and boreholes. In the theory of electrical prospecting, the main goal is to define and solve firstly direct and then inverse problems. Simply speaking a direct problem of geoelectricity is to find a field for a known object with given physical properties, inverse is to find the parameters of the object using a given field. The solution of the direct problem is unique, but this is not unique for inverse problem which is ill-posed. Solutions can be found by solving the system of Maxwell's equations numerically.

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Introduction to EM techniques

EM exploration is a part of geophysical exploration aimed to study geological structures with help of electromagnetic fields. It allows solving many problems from shallow surface civil infrastructure needs to deeper geological structures mapping and archaeological studies to deeper geological structures mapping and also about High Resolution EM technique. It allows solving many problems from shallow surface civil infrastructure needs to deeper geological structures mapping and archaeological studies to deeper geological structures mapping and also about High Resolution EM technique.

It has been a decades like EM methods tried to prove its deserved place on HC exploration market. Proved original techniques caused diverse opinion when it comes to the Norwegian explorations sector from 'how brilliant it is' to 'it is totally failed on Norwegian shelf'. Why are experiences so different? What makes disappointments as frequent as success stories - lack of explorationists experience in EM or may be absence of appropriate interpretation tools? The Editorial team of The First tried to understand and presenting here the challenges of EM exploration and precaution of what has to be taken into account when exploring with EM.

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SPE Norway – EM

High Resolution EM and RALF 1 software

The editorial team of The First Magazine was the first who met Vadim Chernov in Norway. The geoscientist who has many publications and experience in thousands of kilometers of processed data, sensitively attacked the exploration world in LinkedIn by giving away his core software free and offered his expertise to Norwegian society, since the end of April 2017. We wanted to use the chance to ask Vadim Chernov about the High Resolution EM method he worked on and advantages of his software.

Also, the editorial team contacted former colleagues of Vadim Chernov, Peter Dubinin, leading Geophysicist in GeoNefegaz and present Chief Specialist KruKO (HRES-IP EM equipment developer) to tell us about Vadim achievements and to comment HRES-IP method and its advantages.

High Resolution Geoelectrical Prospecting, Inversion Software RALF 1 and its Success Rate

The history of method presented in this article began in 1970s. Alexander Kulikov was Russian scientist who worked at the Research Institute of Geophysics in Moscow, created the IP based method with phase measurements at infra-low frequencies (near 1 Hz), one of the most effective method to search for ore deposits. He discovered relationship between phase of the IP and the apparent polarizability. This analysis allowed to determine the presence of polarized objects in the geological structures. Later, Andrey Goryunov and Eugeny Kiselev from the same institute, suggested using this method for exploring hydrocarbons (HC). They believed that HC rocks behave as polarized objects on the edges. Since 1995, Vadim Chernov has been working on developing software for this method. The method was based on later created inversion IP program complex (2002), where Vadim Chernov is co-author, and the method was renamed to High-Resolution-Seismics (HRES). The HRES-IP was applied from 2002 to 2011 in different regions of Russia and abroad. The right to the method belonged to the company JSC RPC Geonethgeaz (not active today). Now this technology is under Russian Federal State Unitary Enterprise FGUP VEI (vGEI GEO*)

In 2011, the set of programs RALF 1 was developed to process and interpret the field material as result of Vadim Chernov’s many years’ experience. RALF 1 was tested in Western Poland, Iran, Kazakhstan, Moscow region. The set allows to make changes depending on EM field to search for ore deposits. Chernov, independent geoscientist in 4th generation, the author of the original inversion program for a high-resolution inversion of the electromagnetic (EM) field, certified author of the computer program RALF 3 (cert.№2016182774) and co-certified co-author of EPIS 2.0 (cert.№20111757) to Russian maximum registration for prospecting fossil fuels. He holds Master of Sciences in Geology from the Moscow State University. 2006-2010, he worked in the Scientific Production Centre of JSC RPC Geonethgeaz where he developed the original program. The base of inversion program forms the part of the software system for data processing and interpretation of a high-resolution induced polarization exploration method (HRES-IP). He has been awarded a Diploma of Merit by the Russian Federal Ministry of Natural Resources for his work.

Software complex RALF 1. Main principles for solution

The author claims that accuracy of performed studies is more than 85%, and the possible layer resolution 3-5 meters for land data. In the sea this complex has no experiences prior to 2017.

Method principle

HC saturated rocks have very low polarizabilities compared to surrounded rocks, and mineral water with just a small HC mix have a very big polarizabilities in a low frequency range. Figure 5. The accumulated electrostatic charge in a changed polarity external field causes currents, which looks like an appearance of negative resistances in the section or an appearance of zones with negative polarizabilities. In some zone such system can be considered as current emitter. HC rocks behaves like a condenser and is distinguished by minimal polarizabilities at frequencies of 1 Hz. At the same time, surrounded rocks behave like rocks having double dialectical layer properties and can be described by Cole-Cole formulas with constant time relaxation in 1 second [9]. In addition, the oil-saturated layer is very anisotropic object. Vadim Chernov refers to Kerr effect (NOLIMORE) [10] as a variant of this nature interpretation. It has a magneto-optical properties (heavy oil is optically anisotropic substance in the electromagnetic field). It is known that the electromagnetic field in a layered medium has two components: flat incident wave (wave part) and the current component, which are connected to each other through a system of Maxwell’s equations, and can be associated non-linearly in the presence of rocks exposed to Kerr effect. Thus, if to calculate the components of the electromagnetic field R (compare to df/d ρ) over a multilayer medium, a recurrent functions are used simultaneously, and these functions describe the laws of horizontal and vertical distribution of resistivity in a section. In this case, there is an opportunity to study both directions. Also, if rocks contain high resistivity HC layer then longitudinal resistance does not give a noticeable changes, but transverse resistance increasing making rock layer super anisotropic. Noticeable changes in anisotropy also can be caused by fraction and optical active C18, C19 components that cause already mentioned Kerr effect. In fact, an actual received amount of change of the anisotropy is 30-50% rather than obtained in the simulation–2-3%. Summarizing, the simultaneous analysis of vertical and horizontal current components of EM field, may provide to find an area of such non-uniformity at reservoir. As result, it makes a conclusion about the presence or absence of HC at a given point of geological section, Picture 6.

Success %

Data 1 changes in magnetic component of the field

Table 1. Recorded success rate statistics for HRES-IP method

<table>
<thead>
<tr>
<th>Company (Fields)</th>
<th>Number of Objects</th>
<th>Discovery, wells</th>
<th>Success %</th>
<th>Dry well, %</th>
<th>Missed reservoir, %</th>
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<td>18</td>
<td>&gt;70</td>
<td>&lt;20</td>
<td></td>
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<tr>
<td></td>
<td>21</td>
<td>67</td>
<td>&gt;14</td>
<td>19</td>
<td></td>
</tr>
</tbody>
</table>

*RALF 1 – Reflection on Actions of Lorentz Forces*

![Picture 6](image6.jpg)

![Picture 4](image4.jpg)

![Picture 5](image5.jpg)
Inversion principle of RALF 1 which makes solution precise

“Everyone knows that inverse problems are incorrect, and the effects that we observe are just decimals of a degree. Even its derivatives with respect to the desired parameters are smooth and weakly differentiated functions. Many scientists gave up their work because of this. I did not give up for many years. And I know how to work with these smooth functions so that they give such a differentiated picture. Now it can be done by everyone in an automatic mode.” Another question - how does it work? But this is not physics problem, but mathematics.” - says Vadim Chernov.

RALF 1 makes possible to obtain the distribution resistances, resistance anisotropy, and the IP processes for 2D and 3D. The algorithm can give not only electrical parameters of geological layers but also quite precise depths. Using big samples of parameters is making solution of inversion problem more clear in borders of Shannon theorem [12].

“The uniqueness of my solution is that I get independent solutions for all unknown parameters that are not correlated with coefficient of correlation 100%. On the RALF 1, you can see not the most exact solution, but something that does not correlate. Picture 7, 8, 9, This is specific of each parameter. So, I remove the background. It is some kind of filtering, not spatial, not time-frequency, but logical. Based on the formula you see [12] (but note that formula is incomplete). Somewhere, the exact solution is sought for every point of probing. In the program table you see the exact solution, but it does not mean that the 2D section should look like an exact solution. You can always remove the background. This is standard practice. The background presents seeing details. To prove it, enter into this formula $K = 1$ the inverse problem that you have, and compare the results without this formula. We checked this in 2007. It was another 3 years, before RALF 1. I think that even with $K = 1$ you will get an indelible impression. In fact, my help won't be needed. May be, 90% of EM land based on high-frequency induced polarization. It means, we are looking for polarization in the upper layers. Usually, a zone of oxidation-reduction reactions and pyrites zone are formed above HC reservoirs. People do not bother and look for pyrites in the upper 500 meters. But what about situations of multi-layer deposits? The problem is that nobody tried to solve inverse EM problem for such volume of frequencies and parameters as we did it. Now we can get information about more than 100 parameters from one sounding in one physical point. Such parameters as polarizabilities, anisotropy of resistivity and thickness for each layers. In most cases of EM frequency probing all polarizabilities are fixed, except one in the perspective depth interval. I suggested mathematical solution. My depths increment is 100-200 m, and for each layer polarization, resistivity, anisotropy of resistivity and polarizability are selected. It is an incorrect problem and hard to understand how is possible in principle. For example, I have 45 parameters are searched on 70 frequencies, which differ very little in derivatives. 2.5 km and 2.2 km are presented with completely different contours. Normally EM can see only one common contour. I see everything separately in a frame of Shannon theorem. This is possible because there is a difference still present between the derivatives of the parameters, when there is enough measured data. This difference is enough to work with. For most of EM methods, granite rocks will be something unified without precise depths, but not for my method. And now, you can see it too. That is the difference. RALF 1 also can see anomalies in prospective layers as low polarizabilities in small areas in a big massive of rocks with highly saturated mineral water and in high level of polarizabilities. RALF 1 can also see hydrocarbon reservoirs in depths of 3-4 km under 1 km of granites, Picture 9. - says Vadim Chernov.

AFSPID* Method and its main features

Today Vadim Chernov suggests AFSPID method. It is modern technique based on RALF 1 program algorithm, allows producing a layer-by-layer analysis of IP, including an anisotropy of resistivity. The main feature of the AFSPID is a possibility to obtain stratification in three-dimensional space of the three main characteristics of reservoir interval - resistivity, resistivity anisotropy, polarizability, and additionally, thickness for each layer.

It is analogous to the High-Resolution Time-frequency EM Surveying Method, but modified in accordance with the technical features of MBH* generator to increase the power of the generated signal. It is intended to calculate HC reserves at the work site, and to perform measurements on an irregular grid.

Analogues and their limitations

Editorial team asked Vadim Chernov if there are any analogues of his method and inversion techniques are present in the World, and what is their success rate. He told, that there is an analogue. Induced polarisation used in different configuration. For example, Spectral Induced Polarization - Resistance Complex - SIP, CR (SIP or CR) is an electrical method that can be used to display changes in the electrical properties of the rocks that are associated with geochemical phenomena of alteration and associated with HC. Positive anomalies caused by polarization in oil fields have been long time observed in Russia since 1990. China conducted detailed studies with 74% success rate. More than 103 structures were drilled in the Eastern part. They used high-power SSIP method. In North America technique were used in Cement, Blanch, and in Oklahoma (USA), and the David Field site was one of the first successes in Alberta (Canada).

“It would be very interesting to work in Norway. EM marine task, e.g. in Arctic region, is very interesting way for RALF-1 hydrocarbon exploration. Here is future. I would like to prove it.” - said Vadim.

The steps drawn on the graph show the modified algorithm results. Mathematically, this was done by means of introducing all parameters of average increment in each increment of optimal parameter. The formula is presented here:  

$$\Delta P = \sum_{i=1}^{n} \Delta P_i$$

where

- $\Delta P$ - optimal increment of the residual on the $k$-th parameter
- $\Delta P_i$ - changed increment of the residual on the $i$-th parameter
- $n$ - number of parameters
- $\Delta P_i$ - magnitude of noise for all parameters
- $\sigma$ - normalisation factor for the modified residual

The additional step which were added to the RALF1 algorithm in order to increase an accuracy of depth computation. The step has an automatic limitation of a weak derivative and subsequent computation of a constant and modified algorithm results. Mathematically, this was done by means of introducing all parameters of average increment in each increment of optimal parameter. The formula is presented here:  

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Russian geophysicist, researcher Vadim Chernov, after graduating the Geological Faculty of the Moscow State University, joined like-minded team of JSC RPC Geoneftegaz, electrical exploration department in 1998. HRES-IP was developed at ISC RPC Geoneftegaz, combining the most promising EM methods used in the world practice for HC prediction.

The basis for the development of this technology was the theoretical and methodological development of the Russian leading research institutions of the early 1990s: VNIGRI (Moscow), NIIGRI (Saratov), SNII RAS (Moscow). The work was aimed to study a specific electric conductivity and an induced polarization of rocks which anomalies are associated with hydrocarbon deposits, in the frequency domain. In the time domain, it allows to perform an analysis of the time and dynamic characteristics of the nonstationary field, and to perform depth tie of electrical anomalies, based on a joint analysis of EM exploration, log data and seismic surveys.

To carry out field exploration, a hardware-software complex developed by KruKo company (by the order of ISC RPC Geoneftegaz) was used. The complex includes a set of field meters AGE-xxl and a number of universal current switches for generator setup.

The processing and interpretation of the HRES-IP data is carried out on the basis of a specialized software package for processing and interpreting - EPIS developed by the specialists of JSC RPC Geoneftegaz (Volkova NB, Dubinin PA, Kalachev AA, and Chernov VV).

In the team, Vadim Chernov was responsible for developing the program of electromagnetic exploration inversion, an extremely important tool for interpretation. In the period of 1998-2010, Chernov developed a one-dimensional inversion program in frequency domain FISI widely used as part of the EPIS complex to inter the data of the HRES-IP both in Russia and abroad. Continuously improving the inversion algorithms, he achieved significant success in solving the basic problem of inversion - increasing the accuracy of estimating geometric parameters, their depth and lateral tie, even in conditions of a three-dimensional inhomogeneous medium. The results of his research of parameters, their depth and lateral tie, even in conditions of a three-dimensional medium, are repeatedly published and reported at international conferences.

It should be emphasized once again that Chernov’s program of FISI inversion is an integral part of the EPIS complex and the HRES-IP technology, which are methodologically integrated in one piece.

What is the history of EM method(s) you use? PGS developed the highly efficient Towed Streamer CSEM technology. The EM source and receivers are both towed behind a single acquisition vessel which is capable of acquiring 2D broadband seismic in the same time as the resistivity data. The driving force for advancing EM acquisition technology was to improve efficiency and to enable resistivity and seismic data to be acquired simultaneously.

What geometrical configuration do you use to acquire data? Towed streamer EM technology is based on tried and tested streamer seismic operations, the EM cable is 8700 m long and contains 72 electrode pairs (receivers), it is towed at a depth of up to 100 m. The EM source is 800 m in length and is towed by the same vessel as the EM streamer (image above). When acquiring 3D EM data PGS designs EM surveys with a line spacing of <1.5 km, enabling the delivery of both 2D resistivity sections, and 3D resistivity volumes.

Who and when solved direct and inverse problem used for PGS EM configuration? Inversion codes have been developed internally (3D Gaussian-Newton code) and externally (2.5D MAREZDEM from the SCRIPPS Institute of Oceanography) with a focus on efficient and accurate implementation. PGS has worked closely with third parties to ensure optimal inversion code performance for high density towed streamer EM data. This flexible approach enables PGS to deliver unconstrained and semi-automatically guided resistivity sections and volumes while also enabling our customers to invert and analyze the field data themselves.

What are the challenges for EM Mariner inversion? One challenge relates to the relatively low transverse resistivity of the overlying Heimdal channel sands and injectites, this results in a low resistivity contrast between the Heimdal sands and the background resistivity which can make imaging more challenging.

With regard to the Maureen reservoir, proximity to highly resistive underlying geology is the primary challenge. This is a good example of imaging uplift provided by Towed Streamer EM data, the high density data acquired using the cable-suspended CSEM streamer allowed PGS to integrate the two to distinguish and characterize more challenging targets than when more sparse data is acquired.

Does your software (name it) allow flexibility to invert other acquired configuration sets? PGS’ own internal code (ITEM) has been designed specifically for Towed Streamer EM data, but as we recognize that the market wants flexibility it has potential to be able to handle node based data as well.

What is the total data acreage PGS acquired today and what is the success rate for Confirmed discoveries, Missed aims, False positives?

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Electromagnetic Geoservices (EMGS) was founded in 2002 and has acquired over 800 marine CSEM surveys worldwide, in water depths ranging from 20 to 3500 m. The method uses a 300 m horizontal electric dipole source towed close to the seabed, generating currents up to 7,200 A. A grid of receivers is placed on the seafloor allowing to record directly the response from the sub-surface as well as minimize the noise levels and positioning errors. The receivers measure inline and broadside components of both electric and magnetic fields, resulting in a low-noise, wide-azimuth 3D dataset designed to provide optimal sub-surface illumination.

Tools for CSEM processing and imaging have matured significantly since 2002. Today, all data are processed through in-house anisotropic inversion software, generating 3D images of both vertical and horizontal subsurface resistivity. EMGS’s 3D inversion has now been in production for almost 10 years, during which time it has undergone continuous improvement addressing, among others regularization, data uncertainty, air-wave mitigation methods, etc. The most recent breakthroughs came last year with the introduction of 3D TTI inversion for steeply-dipping geology [Hansen et al. SEG 2016], and a 3D Gauss-Newton update scheme for greater model robustness in complex geological settings [Nguyen et al. SEG 2016].

The final piece of the puzzle to successful use of CSEM information lies with our customers: the additional subsurface information must be successfully embedded into existing interpretation workflows, leading to quantitative updates to exploration predictions. To assist with this task, EMGS has developed a suite of software tools and workflows [e.g., Baltar & Barker, FB 2015]. Today, with the combination of wide-azimuth 3D data, mature anisotropic inversion schemes, and integrated, quantitative interpretation, we see our customers achieving an excellent return on their investment in CSEM [e.g., Zweidler et al, 2015].

EMGS’s global multiclient library covers over 70,000 km². In the Barents Sea, CSEM data are available for all major discoveries and show clear responses. Smaller discoveries (<100 mmbls) are visible if they fall within the sensitivity limit (which can be assessed in each case of interest). The data library covers many of the 24th round and APA 2017 blocks.

A small data example shown in the figure comes from a recent survey in the Hoop area. In most surveys, the CSEM source energy, optimized to achieve both a good spatial resolution and a sufficient penetration depth, is distributed within the frequency range 0.1 – 4 Hz. However, the Hoop area is characterized by exceptionally high subsurface resistivities and shallow target depths, hence the optimal frequency range here is higher. With some hardware and processing improvements, EMGS was able to acquire data at the record high frequency of 48 Hz, which resulted in an improved spatial resolution. The figure demonstrates sensitivity to hydrocarbon reservoirs of only 1-2 km² area, and gives an optimistic prediction about the soon-to-be-drilled Gemini North well.

Referenced EMGS publications are available at [http://www.emgs.com/technical_papers/].
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