Oil Gas

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DRILLING

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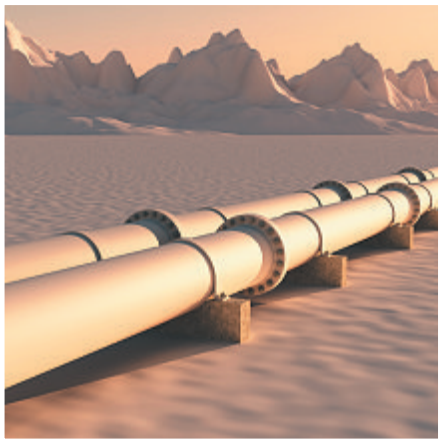

Gas from Russia for Europe

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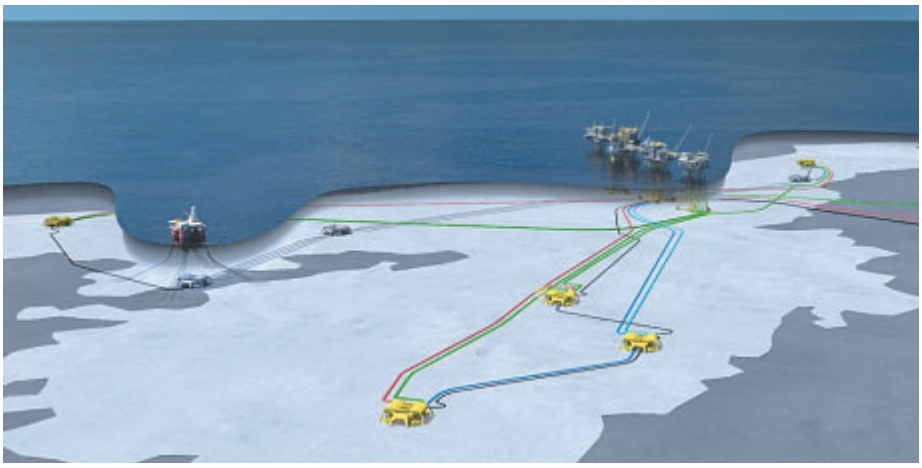
Plan for Johan Sverdrup phase 2 approved



The plan for development and operation (PDO) of the second phase of the Johan Sverdrup field development was formally approved by Norwegian authorities on 15 May. The same day sees the construction start of the field's second processing platform at Aibel's yard in Haugesund.

"This is a big day for Equinor and the other Johan Sverdrup partners comprising Lundin Norway, Petoro, Aker BP and Total. Johan Sverdrup is a world-class field that will provide value to its owners and society for 50 years ahead with record-low emissions. This truly marks the beginning of the second development phase," says Anders Opedal, executive vice president for Technology, Projects and Drilling in Equinor.

Johan Sverdrup is the biggest field development on the Norwegian continental shelf since the 1980s. Phase two of the development, with planned start-up in Q4 2022, will increase field production from 440,000 boepd to 660,000 boepd.

The second development phase has a capital expenditure of NOK 41 billion (4.2 billion €). In addition to construction of a new processing platform (P2), the development will also include modifications of the riser platform, five subsea systems, and preparations for power supply from shore to the Utsira High in 2022.

The first phase of the Johan Sverdrup development is approaching 90% finished and production is expected to start in November this year.

Only a year after the drilling platform was completed and sailed away from Haugesund, the construction of another topside is kicked off at the Aibel yard in Haugesund.

"Johan Sverdrup has played an important role to suppliers and local communities in Norway, including Aibel and Haugesund. With the construction of the second processing platform kicked off here at Aibel's yard on Risøy, the Johan Sverdrup project will once more become a landmark in Haugesund, which is great," says Trond Bokn, senior vice president for the Johan Sverdrup development in Equinor.

In the first phase of the Johan Sverdrup development more than 70% of the contracts were awarded to suppliers in Norway. Despite continued strong international competition, the Norwegian share will probably be even higher in the second development phase.

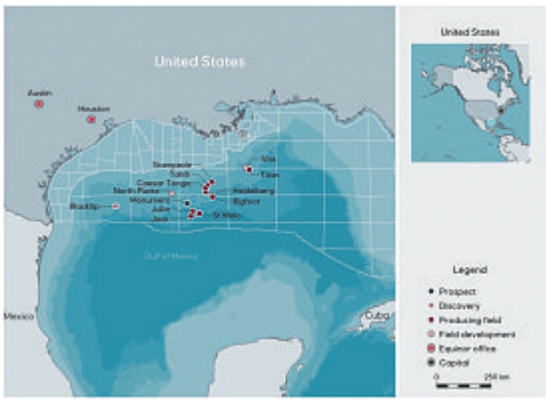
The contract awarded to Aibel for construction of the second processing platform for Johan Sverdrup will help employ up to 1,500 people in Haugesund during the construction phase. The Agenda Kaupang analysis agency estimates that the Johan Sverdrup field development may contribute to more than 150,000 man-years in Norway in the period 2015–2025.

The Johan Sverdrup field is powered from shore, placing it among the oil and gas fields with the lowest CO_2 emissions in the world. In the second phase the field will also supply shore power to other fields on the Utsira High, including the Edvard Grieg, Gina Krog and Ivar Aasen fields. Emission reductions from Johan Sverdrup alone are estimated at more than 620,000 t of CO_2 on average per year, corresponding to annual emissions from 310,000 private cars.

■

Equinor to increase share in high value asset in deepwater US Gulf of Mexico

Equinor has exercised its preferential rights to acquire an additional 22.45% interest in the Caesar Tonga oil field from Shell Offshore Inc for a total consideration of USD 965 million in cash. This will increase Equinor's interest from 23.55% to 46.00%. Anadarko remains the operator with a 33.75% interest, and Chevron retains its 20.25% interest.



The Caesar Tonga field is located 290 km south-southwest of New Orleans in the Green Canyon area and is one of the largest deepwater resources in the US Gulf of Mexico. Equinor's current share of production from Caesar Tonga is 18,600 boepd (net to Equinor).

Since 2005 Equinor has built up a sizable position in the Gulf of Mexico. In the first quarter of 2019 Equinor's equity production was 110,000 bpd, making it one of the largest producers in the Gulf of Mexico.

The transaction will have an effective date of 1 January 2019. The closing of the transaction will be subject to customary consents and approvals.

Equinor has been present in the US Gulf of Mexico since 2005 with exploration prospects and interests in eight producing fields and two in development. Equinor is the owner and operator of the Titan facility. This year Equinor is planning to drill the Monument Paleogene prospect in the US Gulf of Mexico.

In addition to its offshore portfolio in the US Gulf of Mexico, Equinor has extensive US onshore operations in the Eagle Ford (Texas), the Bakken (North Dakota) and the Appalachian basin (Ohio and Pennsylvania).

■

Statfjord A coming home to Stord

The Statfjord A platform in the North Sea will shut down production in 2022, 43 years after first oil. This more than doubles the expected lifetime of the platform. Now the contract for removal and disposal of the topside has been signed, and the topside will be demolished at Stord – where it was built in the 1970s.

The contract for the engineering work, preparations, removal and disposal of the topside has been awarded to Excalibur Marine Contractors, a company in the Allseas group. Kværner AS at Stord has been hired by Excalibur to dismantle and recycle the topside onshore.

The 48,000 t topside structure will be removed from the concrete legs in one single lift by the Allseas vessel the Pioneering Spirit: "The vessel has done an excellent job installing three of the four Johan Sverdrup topside structures. Now they get to show their strength at the other end of an oil field's life cycle," says Peggy Krantz-Underland, Equinor's chief procurement officer.

The vessel has never performed a lift this heavy. It currently has a lifting capacity of 48,000 t, equal to the weight of the Statfjord A topside structure. The capacity will be increased prior to the lifting operation.

One of the oldest platforms on the Norwegian continental shelf, Statfjord A was originally scheduled to be shut down in 1999. It has since then undergone substantial upgrading and the platform life has been extended several times.

Since first oil on November 1979 the Statfjord field has produced more than five billion b of oil and gas.

"Statfjord A has meant so much to many people. The platform has generated enormous values, many jobs and a proud history. Shutting down production and removing the installation is part of a platform's life cycle, and we will make sure that this is done in a safe manner, while taking care of personnel and capabilities in a late life phase," says Hege Flatheim, vice president for Statfjord operations.

All environmental aspects of the decommissioning will be handled in accordance with the highest industry standard and with a recycling grade as high as possible.

The two other platforms on the field, Statfjord B from 1982 and Statfjord C from 1985, will remain on stream until 2025, at least.

The impact assessment for the Statfjord A removal was issued for public consultation in the autumn of 2018, and preparations for shutdown and decommissioning have long been underway. The next step now is to submit the disposal part of the decommissioning plan to the authorities.

"It will describe the proposed disposal solution and timing of the final shutdown of production for Statfjord A. We also plan to start permanent plugging of wells on Statfjord A this year using the platform's drilling facilities," says Thomas Bjørn Thommesen, Equinor's project director for decommissioning projects.

The Statfjord Partnership: Equinor Energy AS (operator) 44.34%, ExxonMobil 21.37%, Spirit Energy Resources Limited 14.53%, Spirit Energy Norway AS 19.76%. ■

Europe

STRATEGY CCUS: Drive to develop low-carbon energy and industry

An ambitious international project to support the development of low-carbon energy and industry in Southern and Eastern Europe got under way with funding from the European Union. Headed by the French geological survey, BRGM, the research partnership combines the expertise of 17 partners from ten European countries in the field of carbon capture, utilisation and storage (CCUS); a technology considered crucial to climate action.

In 2017, the International Energy Agency warned that CCUS technologies were not developing fast enough to meet emissions reduction targets laid out in the Paris Agreement. The STRATEGY CCUS project aims to meet this challenge in eight regions identified as promising for CCUS by producing local development plans and business models tailored to industry's needs.

The plans will also define CO_2 transport corridors between local CCUS clusters of industry, and connecting with North Sea CCUS infrastructure, in order to reduce costs and contribute to a Europe-wide CCUS infrastructure.

The project team, which intends to develop plans in close cooperation with stakeholders, will also provide methodologies and examples of best practice for potential CCUS developers, for areas such as public acceptance, stakeholder engagement, life-cycle analyses and techno-economic assessments. The promising start-up regions were selected within 7 countries – Spain, France, Greece, Portugal, Croatia, Romania and Poland – representing 45% of Europe's CO_2 emissions from the industry and energy sectors (EEA, 2016). They feature elements considered ideal for CCUS development, such as clusters of industry, CO_2 storage and/or utilisation opportunities and the potential for hydrogen production and use.

Dr Fernanda Veloso, of BRGM and project coordinator, said: "STRATEGY CCUS is crucial to paving the way for operational CCUS sites from the early 2020s, as it will elaborate on the feasibility plans of promising regions and take into account technical, economical and societal aspects. Countries bordering the North Sea are already discussing plans for CCUS development and offshore geological storage. There is thus an urgent need for the rest of Europe to engage in strategic planning for CCUS development, giving priority to local solutions before looking at wider European connection schemes."

■

North America

BP approves Thunder Horse South Expansion Phase 2

BP has sanctioned development of the Thunder Horse South Expansion Phase 2 project in the deepwater Gulf of Mexico. The project will further boost output at one of the largest oil fields in the Gulf of Mexico and marks BP's latest major investment in the U.S. offshore region.

The project is expected to add an estimated 50,000 gross boepd of production at its peak at the existing Thunder Horse platform, with first oil expected in 2021.

This upstream major project will add two new subsea production units roughly two miles to the south of the existing Thunder Horse platform with two new production wells in the near term. Eventually eight wells will be drilled as part of the overall development.

Thunder Horse South Expansion Phase 2 follows several other major expansion projects at the offshore platform in recent years. An earlier South Expansion project at Thunder Horse started up ahead of schedule and under budget in early 2017 and raised output at the facility by an additional 50,000 boepd. Last October, Thunder Horse Northwest Expansion project came online and is expected to boost production by an estimated 30,000 boepd. And in 2016, BP started up a significant water injection project at Thunder Horse to enhance oil production at the field. Earlier this year, BP announced that recent breakthroughs in advanced seismic imaging had identified an additional 1 billion barrels of oil in place at the Thunder Horse field, highlighting the potential for further development opportunities in the future.

Over the last five years, BP's net production in the Gulf of Mexico has increased by more than 60 %, rising from less than 200,000 boepd in 2013 to more than 300,000 boepd today. BP anticipates its production in the region growing to around 400,000 boepd through the middle of the next decade. ■

Chevron will not increase offer to acquire Anadarko

Chevron Corporation announced that, under the terms of its previously announced Merger Agreement with Anadarko Petroleum Corporation, it will not make a counterproposal and will allow the match period to expire. Accordingly, Chevron anticipates that Anadarko will terminate the Merger Agreement.

"Winning in any environment doesn't mean winning at any cost. Cost and capital discipline always matter, and we will not dilute our returns or erode value for our shareholders for the sake of doing a deal," said Chevron's Chairman and CEO Michael Wirth. "Our advantaged portfolio is driving robust production and cash flow growth, higher investment returns and lower execution risk. We are well positioned to deliver superior value creation for our shareholders."

Upon termination of the Merger Agreement, Anadarko will be required to pay Chevron a termination fee of $1 billion. Consistent with Chevron's commitment to superior shareholder returns, the company plans to increase its share repurchase rate by 25 % to $5 billion per year. ■

Austria

25 years of partnership with Abu Dhabi

It is exactly 25 years since Abu Dhabi and Austria signed a consortium agreement that laid the foundation for the strong and enduring commercial partnership. Core to this relationship is Mubadala's shareholding in OMV based on the fact that Abu Dhabi acquired 13% of OMV shares from Österreichische Industrieholding AG (ÖIAG) in 1994. Later, Abu Dhabi increased its stake to 24.9% and in 2019 all the shares were transferred to Mubadala Investment Company.

The partnership between Abu Dhabi and Austria developed further in 1997 with initial acquisitions in Borealis a leading provider of innovative solutions in the fields of polyolefins, base chemicals and fertilizers. Building upon this partnership, OMV's wholly-owned subsidiary PCD Polymere GmbH was transferred into Borealis a year later. As a confirmation of their confidence in Borealis' business, these holdings were subsequently increased and today Mubadala and OMV shareholdings are 64% and 36% respectively. These investments were a big step in the direction of petrochemicals.

A key factor in OMV's successful activities in Abu Dhabi was the opening of a representation office in 2007. Since 2011, OMV Abu Dhabi has served as an upstream subsidiary for fostering the relationship with the Abu Dhabi National Oil Company (ADNOC), screening new business opportunities and coordinating existing activities in North Africa and the Middle East.

Earlier this year in 2019, the foundations were laid for OMV to establish a major downstream oil position in Abu Dhabi, with OMV acquiring a 15% stake in ADNOC Refining and a 15% share in a yet-to-be established Trading Joint Venture. With this acquisition, OMV is set to become a strategic partner in the fourth largest refinery in the world, part of the Ruwais mega-site, which is integrated into petrochemicals. ■

Hungary

MOL hits dust in North Sea well

MOL Norge, a Norwegian unit of the Hungarian oil company MOL, is in the process of concluding the drilling of a wildcat well in the North Sea offshore Norway. The well is dry.

The well 2/6-6 S has been drilled about 45 km east of the Valhall and Ekofisk fields and 20 km north of the Norwegian-Danish border in the Mandal High area. It is located in production license 860 where MOL Norge is the operator and Lundin and Petoro are partners with a 40% and 20% interests, respectively. The well targeted the Oppdal and Driva prospects. They were both dry. Lundin said that the main objective of the well was to test the reservoir properties and hydrocarbon potential of the Paleocene sandstones in the Oppdal prospect and of the deeper Rotliegendes sandstones in the Driva prospect, located in the Mandal High area. The well encountered the expected Paleocene and Rotliegendes intervals but with no hydrocarbons present. The second Mandal High area dual target well, Vinstra/Otta on the adjacent PL539 license, will be drilled in 2019, Lundin said. This is the first exploration well in production license 860, which was awarded in APA 2016.

The well 2/6-6 S was drilled to a vertical depth of 3,576 meters and 3,843 meters measured depth below the sea surface, and it was terminated in the Rotliegend group. ■

North America

LNG production starts up at Cameron LNG export terminal in Louisiana

The Cameron LNG project has achieved first LNG production from train 1. The project will begin exports in the coming weeks. This achievement is the result of work carried out Total entered the Cameron LNG project through the acquisition of Engie's upstream LNG business in 2018. Phase 1 of the Cameron LNG project of 13.5 million t/a capacity includes three LNG trains of 4.5 million t/a each. Construction is ongoing for train 2 and 3 with first production expected by the turn of the year and mid-2020 respectively.

The project is operated by Cameron LNG LLC jointly owned by Sempra Energy (50.2%), Total (16.6%), Mitsui & Co., Ltd. (16.6%) and Mitsubishi/NYK (16.6%). In addition, the Cameron LNG co-owners are currently discussing a potential expansion of the base project, already authorized by the Federal Energy Regulatory Commission (FERC), that would add two liquefaction trains of 4.5 million t/a capacity each and two LNG storage tanks.

Total is the second-largest private global LNG player, with an overall LNG portfolio of around 40 million t/a by 2020 and a worldwide market share of 10%. With 21.8 million t of LNG sold in 2018, the Group has solid and diversified positions across the LNG value chain. Through its stakes in liquefaction plants located in Qatar, Nigeria, Russia, Norway, Oman, the United Arab Emirates, the United States, Australia, Angola and Yemen, the Group sells LNG in all global markets.

■

Africa

Total agrees with Occidental to contingent acquisition of Anadarko's assets in Africa

Total announces that it has reached a binding agreement with Occidental to acquire Anadarko's assets in Africa (Algeria, Ghana, Mozambique, South Africa) for a consideration of 8,8 billion US-$ in the event of a successful completion of Occidental's ongoing bid for Anadarko. The transaction is contingent upon Occidental entering into and completing its proposed acquisition of Anadarko and to approval by the relevant authorities and is expected to close in 2020.

The assets to be acquired are:

Algeria: 24.5% participating interest and operatorship of blocks 404a and 208 (Hassi Berkine, Ourhoud and El Merk fields) in the Berkine basin in which Total already owns 12.25%. These fields represented a gross production of 320,000 boe/d in 2018.

Ghana: 27% participating interest in the Jubilee field and 19% participating interest in the TEN fields. These fields represented a gross production of 143,000 b/d in 2018.

Mozambique: 26.5% participating interest and operatorship in Area 1 where a 12,8 million t/a LNG project is largely derisked and close to sanction. Area 1 contains more than 60 Tcf of gas resources, of which 18 Tcf will be developed with the first two train project which is expected to come into production by 2024.

South Africa: exploration licences, close to Total's recent Brulpadda discovery.

Overall, these assets represent around 1.2 billion boe of 2P reserves, of which 70% is gas, plus 2 billion boe of long term natural gas resources in Mozambique. 2018 equity production was 96,000 boe/d and is expected to grow to around 160,000 boe/d by 2025.

Total is committed to execute smoothly this transaction, should Occidental be successful in its offer to acquire Anadarko. The proposed transaction is a win/win for Total and Occidental. Total would get access to around over 3 billion boe of resources and Occidental would be able to strengthen its post completion balance sheet by monetising immediately the international assets of Anadarko.

Despite the capital investment in Mozambique LNG, the acquisition is expected to be free cashflow positive from 2020 even at a Brent price of less than 50 US-$/b and to generate more than 1 billion US-$/a of free cashflow from 2025 onwards after start-up of Mozambique LNG.

As a consequence, Total confirms that the previously announced shareholder return policy from 2018 to 2020 will be maintained in terms of dividend increase (10% over 3 years) and share buyback (5 billion US dollars). ■

North America

Shell starts production at Appomattox in the Gulf of Mexico

Royal Dutch Shell plc, through its subsidiary Shell Offshore Inc announced that production has started at the Shell-operated Appomattox floating production system months ahead of schedule, opening a new frontier in the deep-water US Gulf of Mexico.

Appomattox, which currently has an expected production of 175,000 boe/d, is the first commercial discovery now brought into production in the deep-water Gulf of Mexico Norphlet formation.

Appomattox is a story of efficiency through innovation. By way of optimised development planning, better designs and fabrication, and expert drilling execution, Appomattox has realised cost reductions of more than 40% since taking final investment decision in 2015. The start of production at Appomattox is only just the beginning of further maximising the flow of resources in the prolific Norphlet surrounding Appomattox.

Shell's global deep-water business has a strong funnel of development and exploration opportunities in Brazil, the US, Mexico, Nigeria, Malaysia, Mauritania, and the Western Black Sea. Production worldwide is on track to reach more than 900,000 boe/d by 2020 from already discovered, established reservoirs. The company continues to be one of the largest leaseholders in the US deep water and remains one of the most prolific offshore producers of oil and natural gas in the Gulf of Mexico. Shell designs and operates its deep-water projects to be competitive and, since 2014, has reduced its unit development costs and unit operating costs by about 45%. ■

Shell announces deep-water discovery in Gulf of Mexico

Shell Offshore Inc. announced a significant discovery at the Blacktip prospect in the deep water U.S. Gulf of Mexico. Evaluation is ongoing and appraisal planning is underway to further delineate the discovery and define development options.

"Blacktip is Shell's second material discovery in the Perdido Corridor and is part of a continuing exploration strategy to add competitive deep water options to extend our heartlands," said Andy Brown, Upstream Director for Royal

Blacktip is a Wilcox discovery in the Perdido thrust belt and was discovered in the Alaminos Canyon Block 380, approximately 30 miles from the Perdido platform and Whale discovery. The find presents the opportunity to augment existing production in the Perdido area where Shell's Great White, Silvertip and Tobago fields are already producing.

Drilling at the initial Blacktip well is still underway and has to date encountered more than 400 ft net oil pay with good reservoir and fluid characteristics. The further assess the structure's potential. Blacktip is operated by Shell (52.375%) and co-owned by Chevron U.S.A. Inc. (20%), Equinor Gulf of Mexico LLC (19.125%), and Repsol E&P USA Inc. (8.5%).

This discovery in a Shell heartland adds to the company's Paleogene exploration success in the Perdido area. Through exploration, Shell has added more than one billion boe in the last decade in the Gulf of Mexico.

LNG Outlook

Who will absorb the LNG oversupply?

The market has been oversupplied for the past few months, despite China's demand continuing to rise and a jump in deliveries to Europe. So what is the outlook for LNG demand for the coming summer and in the fourth quarter? With US LNG exports to ramp up over the second half of 2019, ICIS takes a global view across the key importing markets.

April marks the beginning of a lower demand season for domestic Chinese gas. Although the prompt spot LNG market into *China* is lucrative on paper compared to domestic prices, high LNG terminal stocks and a lack of storage capacity has curtailed spot demand. LNG demand from industrial and chemical sectors has been dented by a raft of monthlong plant safety inspections triggered by a recent major accident at a chemical plant. A mild winter, which capped LNG consumption for winter heating, has also contributed to high LNG terminal stocks. Chinese importers are trying to reduce these by cutting prices of truck-delivered LNG.

Spot LNG prices are lower than even the lowest city-gate price. Prices at coastal cities are much higher, with Shanghai at around US-$ 8.7/MMBtu. But most domestic city gas companies are unable to profit from the arbitrage, as they lack access to local terminals. Chinese independent buyers Shenergy Group and Guanghui Energy do have the ability to buy incremental spot cargoes.

But China remains the LNG growth market globally, and monthly increases in LNG imports relative to one year ago are likely to continue. The market will closely monitor interest from the major Chinese buyers.

South Korea's steady drop in LNG imports in the first quarter of 2019 could continue into the summer even as concerns grow about air pollution from coal-fired plants and the government cuts taxes on LNG imports. South Korea's nuclear generation operated at close to 90% of total capacity in early April, following the restart of two reactors at the Hanul nuclear power plant last month. South Korean nuclear availability is now higher than at any point in 2018, reducing demand for LNG in the power mix.

Further nuclear additions are expected over the second half of 2019. Some dynamics of the South Korean energy market suggest a summer demand upswing for spot prompt cargoes after a tax cut in LNG imports came into effect on 1 April as duties on imported coal were hiked. But sources are doubtful this in itself will drive a switch towards gas.

South Korea has shut four older coal plants with a capacity of 2.1 GW from March to June to reduce air pollution.

The country relies heavily on coal for power generation and because of the sunk costs in existing plants, the country faces hard choices on pushing the wider use of LNG, even as the world's third-largest importer.

Last winter, rules came in to reduce the level of particulate matter to cut pollution on particularly bad days. This could see oil and coal power plant generation reduced with gas stepping in. But the measure was only implemented on six days in the recent winter.

Shipments to *Japan* were down by over 2 million t in the first three months of 2019 on mild winter demand and higher nuclear power generation, with local end-users facing high stocks at domestic terminals. Although Japanese buyers may buy incremental cargoes ahead of the summer, spot demand is expected to be capped as some utilities expect their inventories could stay high. Japanese nuclear availability is expected to be up by about 36% year on year, according to calculations by ICIS, up from around 49TWh in 2018 to almost 67TWh in 2019. But nuclear generation is expected to flatten out in the third quarter of 2019 to similar levels as the previous year as maintenance kicks in. In the event of a sustained heatwave, as happened in last summer, LNG demand could rise back, with utilities leveraging gas generation at short notice to cover demand for cooling. 2019 will see Japanese buyers become more prominent in the US LNG market. Chubu Electric and Osaka Gas are the two largest marketers from Train 1 at Freeport LNG, with Mitsui and Mitsubishi each taking a third of supply from the Cameron LNG project.

India will remain an important source of spot demand for the rest of the year, with buyers keen to absorb gas when the price is competitive relative to oil products. But the domestic gas market has slowed and the outlook for additional demand from new import terminals is limited. Indian imports fell in the first three months of this year and local sources said the upcoming federal election, which will be held from April to May, had curbed downstream gas consumption from the industrial sectors. This resulted in high stocks at the Dahej and Hazira import terminals, which account for around 90% of India's imports. Developer H-Energy has tendered for cargoes into the new Jaigarh terminal from October 2019 but supply can be delivered to other Indian terminals in case of issues at Jaigarh.

Commissioning of the Mundra terminal also remains uncertain, with project partners GSPC and Adani still working out a concession agreement before the project can proceed to commissioning.

The Ennore LNG terminal on India's east coast was commissioned in March, but is not expected to take more than two to three cargoes this year because of limited pipeline connectivity, said a source from operator Indian Oil. Indian February gas consumption dropped to a two-year low, according to data from India's Petroleum Planning and Analysis Cell, down by 2.1 % year on year.

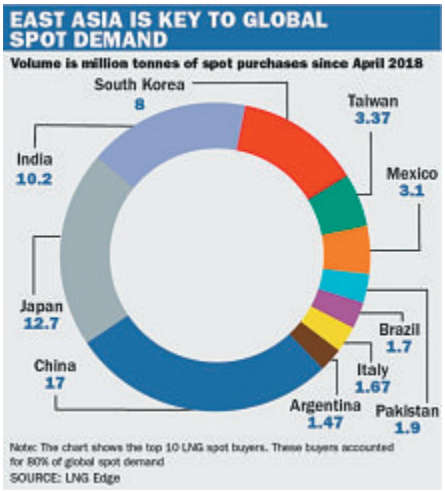
Middle Eastern LNG buyers have not yet been tempted by lower prices, preferring to meet demand with pipeline supply where possible. Kuwait was the biggest regional LNG importer in both 2018 and the year to date. State buyer KPC had approached the market in March with a tender for April delivery but later withdrew it, and traders said it had not signalled buying interest since. The second-biggest buyer in 2018 was Egypt, but rising domestic production means the country has been selling cargoes via tender rather than buying them.

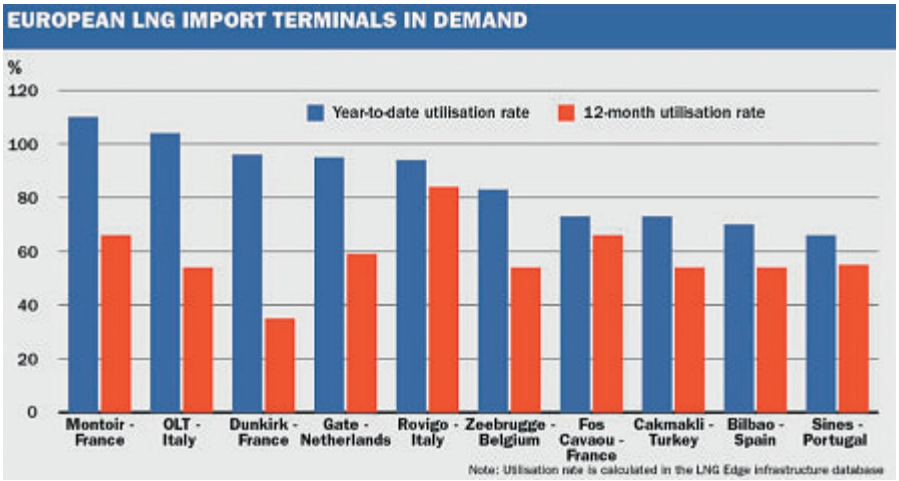
Domestic fertiliser producers in *Egypt* have reported much improved feed gas to their plants this year. *Jordan* is well supplied from Egyptian pipeline imports and a long-term LNG contract with Shell. The government restarted imports from Egypt in September last year and in January signed a deal to increase flows to meet around half the country's daily gas demand of 9.3 million m³/day, with the other half coming from the existing 1 million t/a LNG supply deal with Shell and modest domestic production. LNG imports have fallen so far in 2019.

A source at the energy ministry doubted demand was high enough to justify spot cargoes, saying on 9 April that Egyptian flows often exceeded their target, rising to as high as 6.2 million m³/day in recent days.

Regional gas consumption tends to peak in the third quarter, so there is still time for spot demand to emerge. But with prices flattening out over the past week, the cheapest cargoes may have already gone.

Tight spreads between global LNG markets suggest *Europe* will remain a preferred opti-





on for flexible and spot cargoes over the summer. Recent European gas prices have been volatile, driven up and down by coal and carbon. This in turn has influenced sentiment globally on LNG with a correlation between gas and LNG likely to continue over the summer. Northwest Europe can absorb LNG but domestic storage sites are well stocked and this could limit demand to move gas into storage over the summer. Terminal utilisation rates, especially in the northwest, have been very high so far this year, with limited scope for further increases in some cases. Utilisation levels in Spain remain among the lowest in Europe.
Strong production from Yamal and a rise in Qatari deliveries to northwest Europe offer stern competition for other suppliers.
Germany's gas-fired power generation is forecast to exceed hard coal power output in 2019, according to the Power Horizon Model. 571Wh of electricity is expected to be produced from gas-fired power plants, while 551 Wh of electricity will be generated by hard coal. This is a first for the German power mix, and is tied to the recent lower gas prices which have filtered through to the forward curve, in part caused by the level of incoming LNG to European terminals. Long term, any influence that LNG has on reducing European gas prices could support gas in domestic power mixes. But for this year, in northwest Europe at least, the scope for gas demand to rise substantially is limited.
In southern Europe, early forecasts of a hot summer could support gas demand for power generation in Italy, which may in turn maintain interest in spot supply into the OLT Toscana terminal on the west coast.
Spain has missed out on the surge of incoming LNG seen into other European terminals. Some contract volume with *Algeria* is now supplied on a flexible basis and has so far this year been absent from the Spanish mix. Possibly this could return, although buyers including Endesa and Iberdrola will soon start to lift from US contractual positions which will offer flexibility.
A hot, dry summer could hit hydroelectric generation and bring Spanish gas back into the mix, supporting LNG demand. But Algerian pipe gas flows may also increase.
In the UK, spot opportunities will persist for LNG sellers but the lack of the major Rough storage site will limit injection demand over the summer.
UK gas demand for power generation was steady in the first quarter, averaging 61 mcm/day, up from 60mcm/day in 2018.
Data from the ICIS power horizon model forecasts that gas for power generation capacity is set to be 34 GW in 2019, the same as 2018. Longer term, the case for cheap gas and LNG to boost a share in the UK generation mix is strong.

Demand for *Turkish* LNG could break record levels in 2019, as the country is taking advantage of falling global prices and its expanded import capacity while renegotiating its supply contracts with Russia via the upcoming TurkStream corridor. However, Turkey's ability to break the record may be held in check by internal market constraints, in the form of government regulated tariffs. In addition, even if the US dollar-denominated price of LNG were to fall further this year, there is a risk that the depreciation of the Turkish lira would make it unaffordable for the Turkish private sector. The currency fell 40% against the US dollar last year and has fallen another 4% this year largely because of internal political turmoil. On top of that, private companies licensed to import spot LNG also have long-term supply contracts with take-or-pay obligations and destination clauses. Unless Turkey succeeds in negotiating the scrapping of these terms in its *Russian* contracts, Turkish companies would be locked out of the global LNG market.
In *Greece*, summer LNG demand has typically been limited to one or two cargoes per month. Greece was a much more obvious spot buyer over the latest winter but this level of interest will not continue into the summer. The Revithoussa LNG import terminal is shut for maintenance from 9 April to 9 May.

Part 2 will be published in issue 3/2019 ■

Subsea Power Grid

Siemens' technologies recognized at 2019 Offshore Technology Conference

Two technology teams were recognized at the 50th annual Offshore Technology Conference (OTC) – Siemens BlueVault™ energy storage solutions and the Subsea Power Grid. Siemens is one of three companies to receive two Spotlight on New Technology (SONT) awards this year. The Spotlight on New Technology (SONT) Awards is a program for OTC exhibitors that showcase the latest, most advanced technologies within the oil and gas industry.

BlueVault™ energy storage is a lithium-ion battery-based energy storage solution suited for both all-electric and hybrid (e.g., diesel-electric) power applications. It's specifically designed to help ensure power continuity and minimize emissions on vessels and offshore drilling rigs as well as for offshore production topsides to improve performance, redundancy principles and gas turbine power plant performance. The solution is highly digitalized and features an advanced condition-monitoring system that monitors the voltage and temperature of individual battery cells to provide state-of-health and state-of-charge transparency of the energy storage solution.

"The development of the BlueVault energy storage solution focused on creating the safest energy storage solution in the offshore and marine industry," said Stig Settemsdal, Siemens' Chief Technology Officer, Offshore Solutions.

The Subsea Power Grid is designed to power subsea production equipment cost-effectively and with minimum risk. A departure from the more conventional approach to powering subsea assets, this technology transforms field developments by moving power distribution equipment like transformers, switchgear and variable speed drives (VSD) subsea, thereby reducing cost and making previously uneconomically recoverable oil and gas resources recoverable.

www.siemens.com/otc2019

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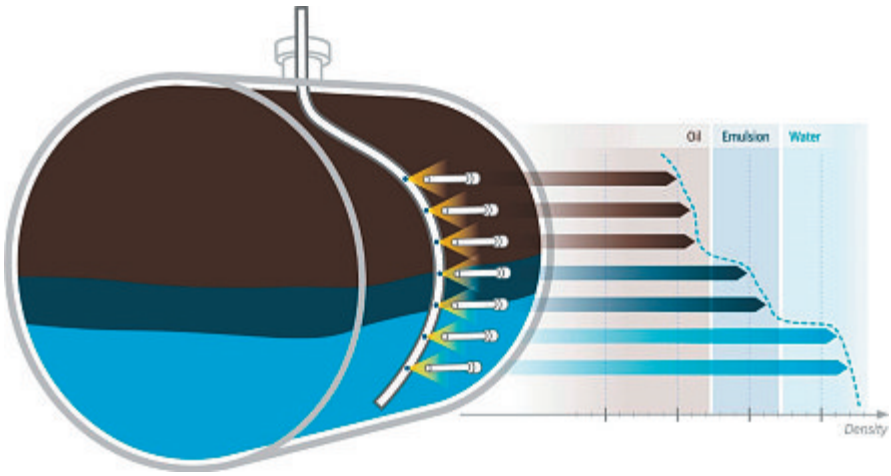
Desalter

Interface Measurement of Oil / Emulsions / Water in Desalters



Interface measurements in desalters are often regarded as not being very critical, even though every drop of oil, to be refined, passes through the desalter. As refineries try to maximize their margins, so-called opportunity crudes are often used. These crude oils generally contain increased levels of sulphur, oil sands, bitumen, heavy oils and oils with high TAN. This can lead to problems with the proper operation of the desalter. In addition, refineries are increasingly confronted with stricter environmental regulations. The efficient level control of water/emulsions/oil layers in the desalter ensures that salts and minerals are effectively removed and that environmental requirements are met. Therefore, more and more operators are turning to radiometry as a highly reliable and accurate measurement solution for this application.

If a clearly defined interface is formed, different technologies can be used for interface measurement. If a larger emulsion layer is formed, for example, when using "opportunity crudes", with a significant density gradient change from oil to water, the measurement with alternative technologies can lead to errors. These cannot determine the height of the emulsion layer and always assume only one separation layer (or interface). This can lead to misinterpretations and the level is either too high or too low.

If the level is too low, hydrocarbons can be entrained with the water/brine effluent and be sent to the waster water treatment plant, where it can cause environmental issues and potential penalties. If the level is too high, it can cause the electrostatic grids to short, therefore potentially allowing water, salts and minerals to be carried over with the crude oil, where water can damage to the distillation columns, salts can cause corrosion issues and fouling of heat exchangers/furnace tubes and minerals such as iron (Fe) can deactivate downstream catalyst.

In addition to controlling water and brine levels, the EmulsionSENS interface measuring system from Berthold Technologies allows you to continuously monitor the gradient change in density to ensure that the water content in the area of the electrostatic grids stays within defined limits, preventing short circuits. In addition, the emulsion layer can be kept continuously at the desired level with the help of an EmulsionSENS, which leads to a significant reduction of the "emulsion breaker chemicals".

"Thus, we reduce the probability of upsets for our customers and maximize throughput in the desalter. This process optimization saves money in the long term", says Berthold.

www.berthold.com/en/pc/news/interface-measurement-oil-emulsions-water-desalters

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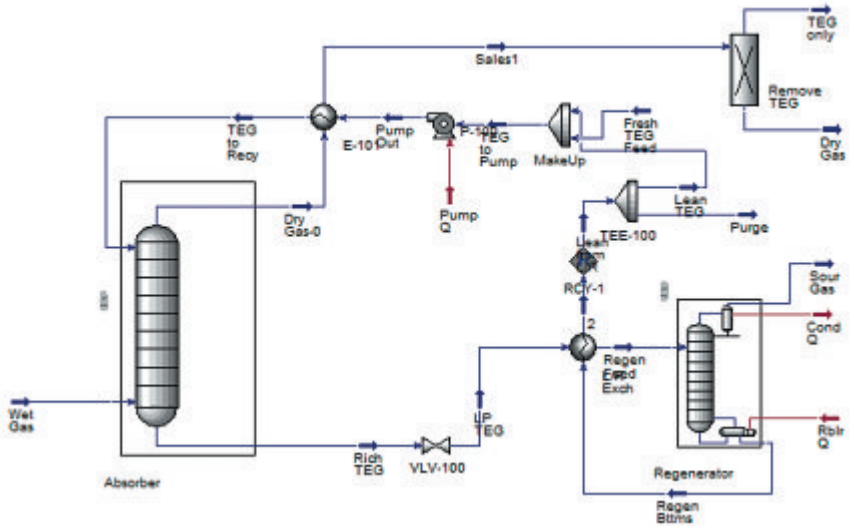
Advanced Process Simulation

Optimizing the Dehydration Process



The dehydration process in gas processing facilities is essential for operators to run operations in an effective and efficient way and meet regulations. When water is present, for instance, gas hydrates can form creating an icy plug in natural gas mixtures, especially when at low temperatures and high pressures. With water, carbon dioxide and hydrogen sulfide present, acid gases form and cause corrosion in pipelines which can lead to damaged downstream equipment

Many governments or agencies regulating shared pipelines maintain restrictions on the water content of sales gas or fungible product. While there are many options for removing excess water, dehydration by a glycol is most commonly used by gas processing facilities. Triethylene glycol (TEG) is most frequently used, but other glycols including diethylene gycol (DEG) and monoethylene glycol (MEG) are also utilized.

There are, however, still some issues with the dehydrator units as they are often overdesigned, resulting in high capital or operating costs. In order to ensure design options meet the necessary requirements of saving capital, solvent, or energy costs, thermodynamic modeling and a holistic view of operations is needed.

A typical glycol dehydrator unit is divided into dehydration and regeneration. For dehydration, first, wet gas enters to the inlet scrubber to remove free water of the gas, and then passes through the contactor. The water-lean glycol enters top of the contactor and flows counter-current to the wet gas absorbing water from the gas. Then the water-rich glycol leaves the bottom of the contactor. The rich glycol is used as a condenser cooling medium for the regenerator gas before it enters the flash tank. Acidic gases and light hydrocarbons in the rich glycol stream evaporate at the flash tank and are used as a fuel. For the regeneration part, the rich glycol stream from the flash tank enters the regenerator, which separates the TEG and water. The glycol is preheated through a heat exchanger by the lean glycol from the reboiler before it enters the regenerator. A stripping gas such as methane and nitrogen can then be injected into the reboiler to help reduce the water contents and reboiler duty. Finally, the regenerated glycol from bottom of the regenerator recycles into the contactor.

The flash gas which evaporated from the flash tank can be used as fuel for the reboiler or as stripping gas. Since the hydrocarbon liquid can cause several problems, such as reducing the efficiency of the reboiler, if the hydrocarbon liquid exists at the condition, a three-phase separation flash drum is needed. Glycol circulation rates determine the water contents in the dry gas and amount and volatile organic components (VOCs) emission from the regenerator as well. The higher the glycol rate, the lower the water contents and higher the venting emission. Therefore, it is important to optimize the circulation rate of glycol to compensate between the two.

In addition to water, another concern for many organizations is the fact that glycol also absorbs methane and BTEX (benzene, toluene, ethyl-benzene, xylene). These are considered hazard air pollutants (HAPs) because they eventually emit into the atmosphere from the glycol regenerator. The BTEX concentration from the top of the regenerator can be 100 higher than that in the raw natural gas due to the concentrating effect of the absorption process. Therefore, although the main purpose of glycol dehydration process is decreasing the water content of natural gas, control of HAPs emission is also integral part of glycol dehydration process. Additionally, some light hydrocarbon may not leave from the glycol in the flash tank, but remain in the glycol and vent from the regenerator.

There are number of process conditions that can affect gas dehydration performance and significantly change results – e.g. TEG recirculation and stripping gas flow rate, temperature, pressure and number of equilibrium states. With all these changing variables, organizations need to have a holistic view of operations to better understand the process and help guide decisions to reduce costs and prevent damage to equipment. One way to do this is by utilizing advanced process simulation tools.

There are currently advanced process simulation tools available that offer property packages specifically designed and tested for difficult to model processes, such as acid gas removal and dehydration. To gain these benefits and more, companies have also implemented a full integrated modeling and simulation engineering environment offering seamless workflows to automatically incorporate equipment sizing, costing, energy networks, and safety systems right in the process model.

For systems involving water, alcohols and hydrocarbons, predicting the thermodynamic behavior is not as straightforward as in other systems. Various thermodynamic property methods have been used for simulating dehydration, such as Peng Robinson (PR) and Soave-Redlich-Kwong (SRK) Equations of State, and some have been developed specifically for the modeling glycol dehydration. Newer property methods, such as the Cubic Plus Association (CPA) Equation of State (EOS), are gaining popularity for accurately representing not only dehydration systems, but also methanol partitioning and mercury partitioning systems. The CPA EOS is similar to the SRK EOS, but it adds an association term to describe the polar effect between molecules.

By implementing an advanced engineering platform, Process Ecology, a Calgary based oil and gas consulting firm, developed an automated process to generate documentation required to meet environmental regulations. Through several successful projects, the company confirmed that the advanced simulation tools with a property package developed specifically for TEG glycol dehydration, they were using had the ability to accurately predict air emissions in glycol dehydration facilities. Consequently, Process Ecology has shown savings up to $30,000 a year for a single dehydrator in energy costs, often through reductions in the glycol circulation rate.

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QHSE

Fire prevention in the oil and gas industry

Fire prevention in the oil and gas industry, as well as in offshore areas, is an ongoing standard designed to protect people and property. In many cases, damage is caused in the area where cables are laid. Specifically, cables are exposed to high loads during peak times; during maintenance work, hidden damage can occur; the cable sheaths are exposed to high UV loads in the open air and become brittle as a result, or excessively high temperatures occur within large bundles of cables. This can quickly lead to short circuits or interruptions, and to the potential for fire. If a fire occurs, it can expand and spread, resulting in severe subsequent damage in areas that are not directly affected. This may lead to cessation of production or a failure of the safety systems. Various protection systems are available in order to contain a fire. The standard systems include rigid panel constructions or multilayer protective sheaths as a sandwich construction, with the required fire resistance values. However, the problem with systems provided today is usually that they are quite inflexible and are difficult to mount. These closed systems also act as a tunnel if a fire occurs. A fire that has broken out can spread unimpeded within the construction and quickly reach a scale that can no longer be controlled. As an alternative, protection systems have now been developed that achieve higher flexibility, are easier to mount and offer an open structure (heat dissipation), as well as the necessary fire resistance times of up to 90 minutes. These are known as fire protection fabrics or bandages. When used in outdoor areas, these systems offer high UV resistance, are suitable for offshore use and fulfil extensive classification standards when it comes to fire resistance times.

www.brandschutzprojekt.de

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Pumping Equipment

German pump technology prevents bore hole icing on offshore platforms

LEWA GmbH has delivered a total of six Ecoflow type LDH5 process diaphragm pumps to the Arabian Gulf in order to expand the pumping capacity of two offshore gas fields.

The pumps are used to inject mono ethylene glycol (MEG) to prevent bore hole icing at critical points along the pipeline. This job follows two earlier major projects. As part of the largest job in LEWA's history, a total of 40 process diaphragm pumps for MEG injection were built for the end customer, an international company, in 2013. A follow-up order in the summer of 2017 included the delivery of 12 Ecoflow series type LDH5 pumps, among other products. The experience, gained on the two previous projects has helped to handle the current, third project with even more speed and efficiency. The major order arrived at the end of March 2018. Its goal was to increase the pumping capacity of two offshore gas fields in Saudi Arabia.

For this purpose, an international oil and gas company ordered a total of six Ecoflow type LDH5 process diaphragm pumps from LEWA.

They are installed on wellhead platforms (WHPs) together with the corresponding M8 pump heads. From there, the pumps will inject mono ethylene glycol (MEG) into the pumping process. This will prevent methane hydrates from accumulating at critical process locations, thereby effectively countering bore hole icing. “The six LDH5 pumps work with an operating pressure of approximately 520 bar and are designed for a flow rate of 5000 l/h,” said Klaus Figgle, Senior Project Manager of Engineering at LEWA.

www.lewa.de

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Investigating the Effects of Operating Parameters on the Increase of the Casing Milling Efficiency in Deep Drilling Operations

*By M. A. NAMUQ, M. J. BERRO and M. REICH**

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Abstract

Tightness of oil/gas boreholes is essential from the economic and environmental point of view. Therefore, casings (steel pipes) are placed into the boreholes and cemented in place to ensure the isolation of the geological zones, the stability of the borehole, the prevention of lost circulation, etc. However, sometimes it happens in deep boreholes that existing casings have to be removed. From an economical point of view, it is often more effective to rebuild an existing pipework than to drill a new borehole. Generally, this is achieved by milling the pipes. This means that there are sometimes milling sections of considerable length.

Nowadays, the milling method is very well advanced. However, the main challenge in a milling process is to achieve fast milling progress with continuous and complete chip removal. In practice this is very hard to accomplish, because the effects of the milling process have not yet in detail been fully understood. The main common problems during casing milling are for example the growth of chip nests around the drill string, the undesired wear pattern of the mills (conical wear of the milling tool), and the production of large casing sheet-like fragments. These all can lead to an uncontrolled milling process, and as a result to increased costs of the milling process. The main objective of this article is to investigate and study the effects of operational parameters and insert types on the milling process in the laboratory, in order to effectively avoid chip nests and casing fragment-forming issues and to provide a controlled milling process.

In the frame of a DGMK project (DGMK project 759), a small model scale casing milling test rig equipped with sophisticated measurement technology was designed and built up at the Institute of Drilling Engineering and Fluid Mining (IBF) of the Technical University Bergakademie Freiberg, Germany, in order to study and conduct basic research on the casing milling process in boreholes. Tens of casing milling tests have been successfully conducted with the casing milling test rig using conventional tungsten carbide inserts and special inserts developed by the scientists of the Technical University Bergakademie Freiberg called FHP-inserts (ultra-hard material inserts). The tests were conducted with different combinations of rotational speeds and forward velocities. The available test results showed that lon-

(Photo: stock.adobe.com)

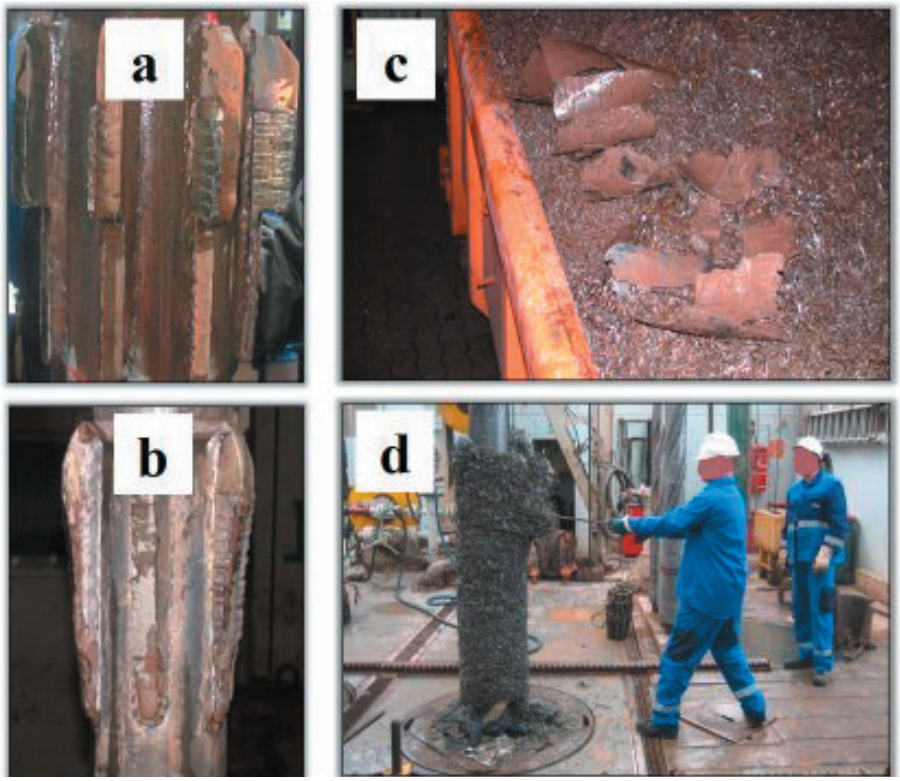

Fig.1 (a) Ideally worn mill [Source: EMPG], (b) A conical worn mill [Source: EMPG], (c) Casing fragments [Source: EMPG], (d) Removal of a chip nest around a stabilizer [Source: Wintershall Dea]

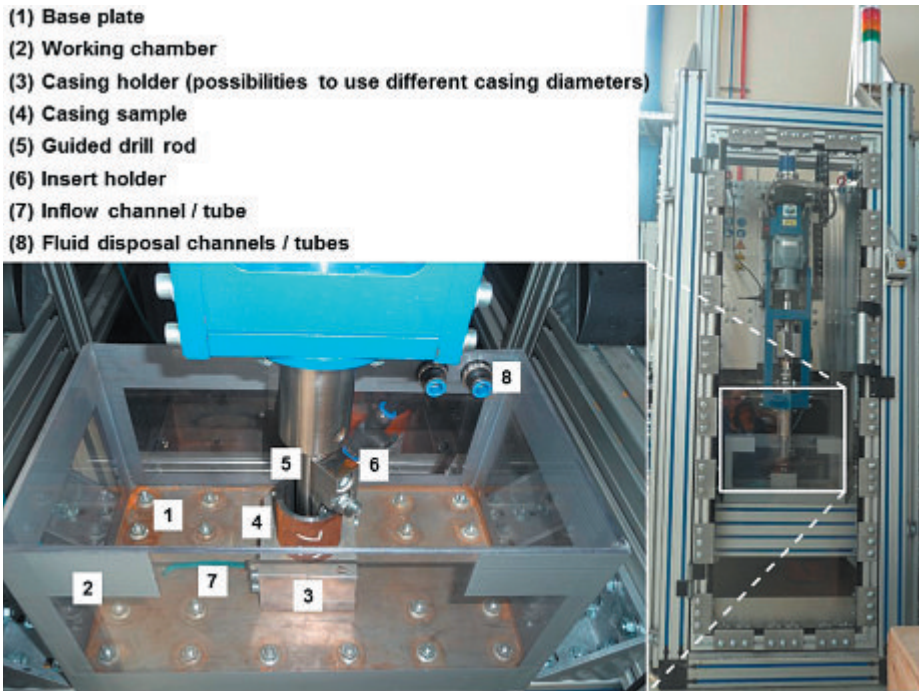

Fig. 2 Small test rig for performing casing milling test

ger chips are formed at high rotational speeds. Furthermore, shorter chips were observed at lower rotational speeds, but the insert wear trend was observed to be relatively higher at lower rotational speeds compared to higher rotational speeds. Additionally, it was observed that the trend of the insert wear increased by increasing the forward velocity for all rotational speeds. The FHP-insert with a cobalt content of 10% seemed to be wear resistant compared to the conventional insert. It can be concluded that in the frame of the first research project phase, a modern test rig with great possibilities to simulate a wide range of milling operation conditions was successfully developed and tested to study and investigate the process of casing milling in boreholes in the laboratory. Moreover, the test rig offers opportunities to test innovative and new ideas, and to study various insert types and insert geometry effects. The results and findings are encouraging. It is highly recommended to continue with the project to perform further laboratory and field tests covering wider operation conditions, and to study the effects of various insert types and geometry designs, in order to statistically validate and to make safe proof of the first phase findings and results. As a result, a milling guideline has to be developed.

Introduction

Boreholes of several decades of age may need to be leak tested and maintained, for instance by replacing the casings due to corrosion or damage. Even during the normal operations, it is occasionally necessary to remove already built-in casings of considerable length such as for sidetracks, and for creation and extension of boreholes. This is generally done by milling casings as it is economically more beneficial than drilling a new borehole. The materials to be milled consist of metallic components (casings) as well as rocks and cement.

In practice, one of the main problems encountered during the casing milling process is the unpredictable and uncontrolled wear of the milling tools. Figure 1 shows the common problems during the casing milling process. Figure 1(a) shows a milling cutter with an almost ideal progressive wear of the tool (worn straight up from the bottom), Figure 1(b) a conical wear, which is quite often encountered in practice. These forms of mill wear not only lead to decreasing progress rates of the milling process, but also enhance the risk of producing large chips (large casing pieces) as shown in Figure 1(c). For instance, due to the conical mill shape, the casings are cut from the inside to the outside. If a piece of the casing breaks off before it is fully milled, it can get jammed in the borehole and can obstruct the drilling fluid circulation, which transports the chips. Another often faced problem during the casing milling process is the development and formation of so-called chip nests around and along the drill string as shown in Figure 1(d). Formation of chip nests leads to obstruction of the drilling fluid circulation system, in the worst case blocking the transportation of the chips to the surface. If a chip nest cannot be removed by a long flushing period, the entire drill pipe must be tripped out of the borehole to get the nest removed. The process of removing the sharp edge chips along the drill pipe has a high injury risk [5].

In the frame of the DGMK project 759, a small test rig was developed at the Institute for Drilling Engineering and Fluid Mining at the Technical University Bergakademie Freiberg to investigate and study the process of casing milling in boreholes. The test rig is a model scale drilling rig with a regulated forward motion dril-

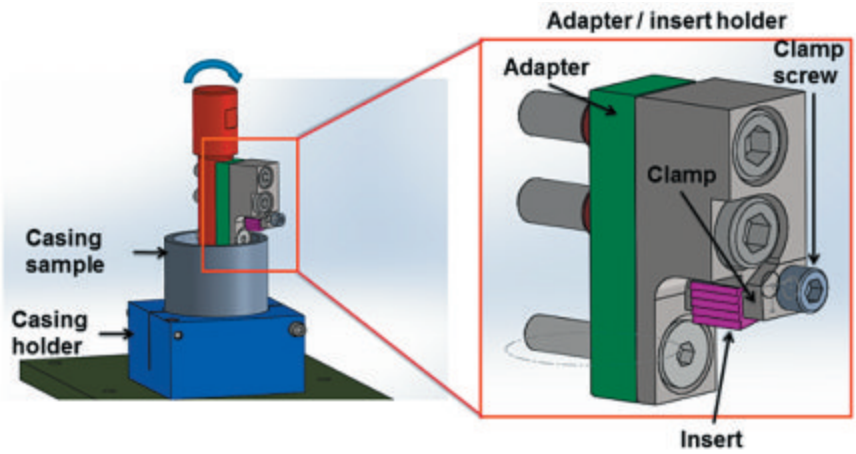

Fig. 3 Clamping claw system

Fig. 4 The prepared casing samples L80 for milling tests

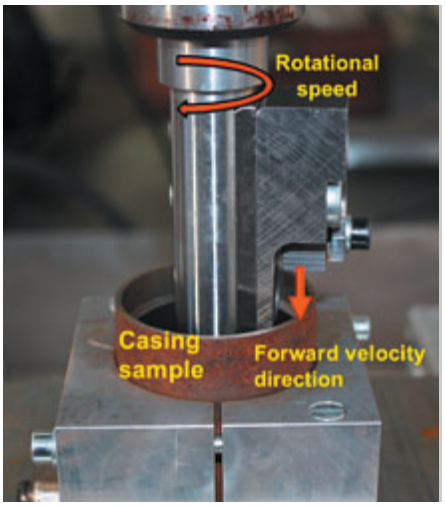

Fig. 6 Explanation of the operating parameters for the casing milling process

(a) (b) (c)

Fig. 5 Shows the inserts (a) conventional striped (b) FHP-insert striped (c) FHP-insert non-striped

ling machine and a gauge shaft, which measures for example the drilling torque and the forward force while milling. Tens of casing milling tests have been planned and successfully conducted with the casing milling test rig. A wide range of operating parameters using the casing type L80 with an outside diameter of 60.325 mm (2 3/8″) and different inserts (the conventional striped insert, FHP-insert striped and FHP-insert non-striped) has been applied and used. Care was taken to ensure that the geometry of the inserts attached on the laboratory milling tool was almost identical to that used in the field. In the laboratory, the influence of the operating parameters such as forward velocity and rotational speed on the formed chip shapes and insert wears has been investigated and studied. Here, different combinations of forward velocities and rotational speeds were taken into consideration. According to the available test results, it was found that the operating parameters have an influence on insert wear and on the formed chip types and chip shapes during the milling process. Nevertheless, it is highly recommended to continue with this study in order to carry out further tests for validating statistically the findings and results.

Experimental Test Setup and Method

Casing Milling Test Rig

In the frame of the DGMK project, an experimental setup was designed and built up at the Institute of Drilling Engineering and Fluid Mining of the Technical University Bergakademie Freiberg, in which single tubes without a cement ring can be milled. The small test rig has been passed through several modification stages since the beginning of the project in order to be usable for experimental investigations of the casing milling process. Each modification stage was performed based on the knowledge gained from the previous stage. The final version of the small modern test rig for investigation of the casing milling process in the laboratory is shown in Figure 2. The base plate (1) in Figure 2 is fixed on the lower side of the working chamber (2), which enables the collection of the produced chips. The individual casing holder (3) is drafted and designed for each individual casing outside diameter (for instance 48.26, 60.325, 73.025 and 88.9 mm). The used cooling fluid (water) for the casing milling process flows through a tube (7) from the bottom of the working chamber into the casing sample (4) and leaves the working chamber through tubes (8). The insert holder (6) holds one insert. The advantage of a single bladed tool is that a defined contact of the insert with the chipping surface exists permanently. In order to use the insert holder (6) for different casing dimensions and wall thicknesses, an adapter or spacer is mounted between the insert holder (6) and the drill rod (5).

The inserts are held by a clamping claw system as shown in Figure 3, which is similar to common machines used in the metal processing industry. In this manner, the inserts can easily be mounted and replaced. Here specific insert holders can be designed and built up for testing and investigating the casing milling process with any specific insert geometry without the need to modify and change the whole experiment.

This test rig has great potential and offers great opportunities to investigate the casing milling process whilst simulating various operating conditions. For this purpose various casing materials and diameters, and various insert materials and geometries can be used. Furthermore, various operating parameters, such as forward velocities and rotational speeds, can be applied during the casing milling process. There are also opportunities to add sensors as required to fully understand and to gain knowledge regarding the casing milling process.

Type of Casings

Due to the small scale of the milling test rig, tubing was used instead of casing, which was supplied by the project partners. The tubing types are similar to the casing types. In this article, it is called only "casing". The casing type is L80. The OD of the casing is 60.325 mm and the wall thickness is about 5 mm. The casing samples provided by the project partners had a length of around 1 m each. Prior to

the execution of the tests, the casing samples had to be prepared by cutting them down to pieces of a specific length of approximately 100 mm. Figure 4 below shows the prepared casing samples (type L80) for the test purposes.

Type of Inserts

The types of inserts provided by the project partners were used also here for these tests. They are named "conventional inserts" in this article. Conventional inserts are equipped with five blades (faces). They are called conventional striped inserts. For comparative and validation purposes, the so-called ultra-hard material inserts (FHP), which were developed by a researcher team at the Technical University Bergakademie Freiberg, were also ordered and tested. Special care was given to the design of the FHP inserts to have the same geometry as the conventional inserts. Two kinds of FHP inserts were ordered and used. They are equipped with five blades (faces) or a single blade (face). They are called FHP-insert striped and FHP-insert non-striped, respectively. Figure 5 below shows the conventional insert and the FHP-inserts.

Rotational Speed

One of the main operating parameters influencing the milling process is the rotational speed. The test rig at the Institute is developed in such a way that this operating parameter can be varied and set to specific values in order to simulate a wide range of casing milling operating conditions. For the executed tests in the frame of this study, the rotational speed was varied from 40 rpm to 175 rpm.

Forward Velocity

In addition to the rotational speed, the forward velocity (Weight on Mill "WOM") is also one of the operating parameters to be investigated. Figure 6 explains the operating parameters of the casing milling test rig. The forward velocity can be varied and set to specific values in order to cover a wide range of operating conditions and to study the influence of this operating parameter on the milling process. The forward velocity was varied from 0.05 mm/s to 0.2 mm/s (0.18 m/h to 0.72 m/h) for the performed tests in the frame of this study.

Chip Shape Classification

The produced chip shapes are important in the casing milling process in boreholes. For the performed experiments on the test rig at the institute, the chip shapes had to be classified and determined for each individual test. As mentioned above, one of the main problems faced in the field during casing milling operations is the forming of chip nests around and along the drill string, which in the worst case will block the drilling mud circulation. As a result, the chips cannot be transported to the surface and the borehole cannot be cleaned from the chips and drilled materials. Therefore, the drill string has to be tripped out of the borehole, the chip nests are removed from the drill string and the drill string is run back into the borehole again to continue the operation. This will not only lead to non-productive time and increased operation costs due to the drill string round trips, but also there is a high human injury risk related to the removal of the sharp edged chips from the drill string. Therefore, the generation of short and discontinuous chips is preferred in casing milling; in this case the cleaning of the borehole is easier, and the likelihood of forming chip nests along the drill string and the related issues is minimized. In the frame of this study, the produced chip shapes are studied

Chip name	Chip shape	Chip shape classification	Rating
Ribbon chip		1	Critical
Snarled chip		2	Critical
Helical chip		3	Critical
Cylindrical helical chip		4	Not preferred
Discontinuous helical chip		5	Preferred
Spiral chip		6	Preferred
Discontinuous spiral chip		7	Very preferred
Discontinuous chip		8	Very preferred

Fig. 7 Chip shape classifications [6], original source: Stahl-Eisen-Prüfblatt 1178-1190 (modified)

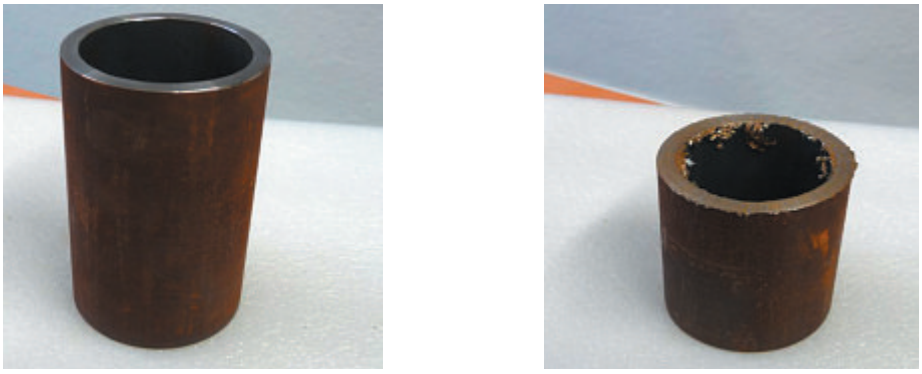

Fig. 8 One of the casing samples L80 before milling (left) and after completing the milling process (right)

Fig. 9 WACKER® silicone oil and glass bottles before (left) and after (right) the test

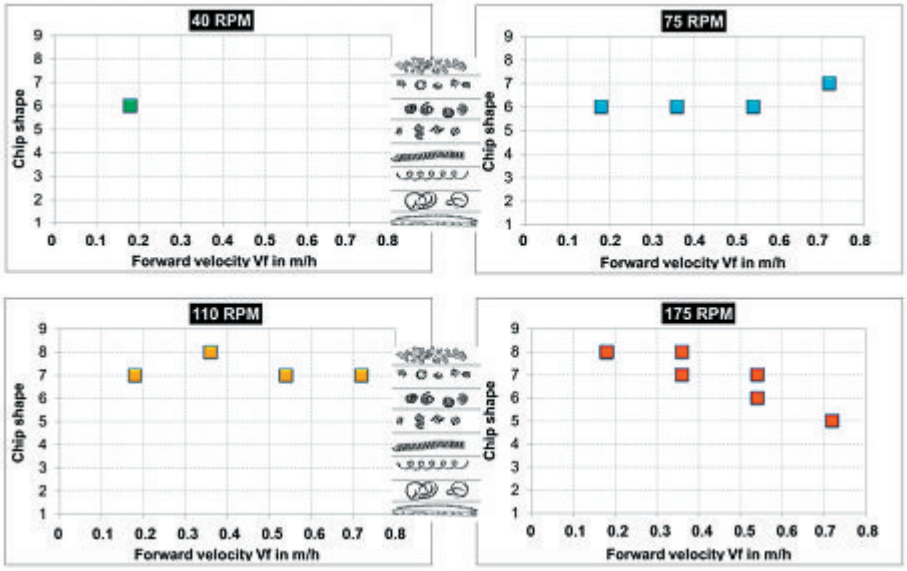

Fig. 10 The produced chip shapes using the conventional insert, and various rotational speeds and forward velocities

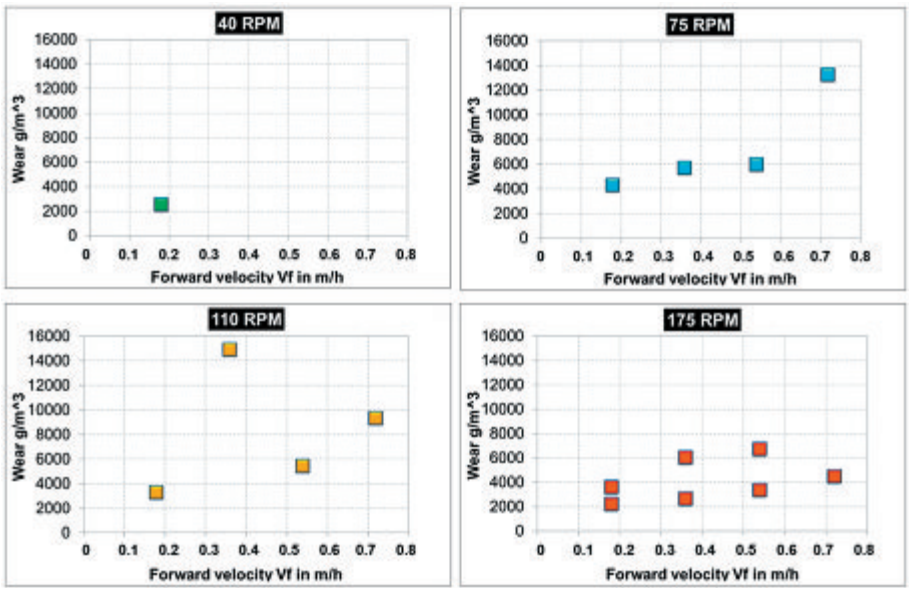

Fig. 11 The conventional insert wear using various rotational speeds and forward velocities

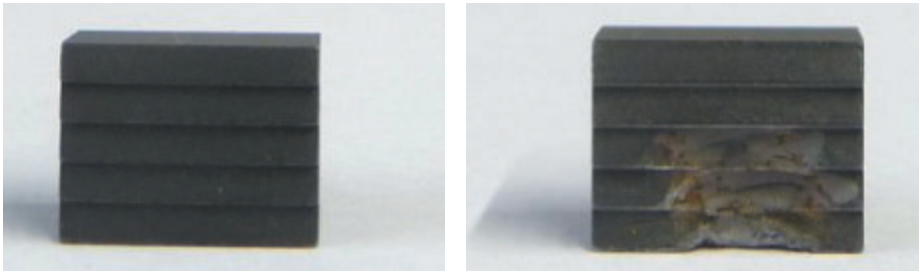

Fig. 12 One of the conventional inserts before milling (left) and after completing the milling process (right

and the influence of the operating parameters on the chip shapes are investigated in the laboratory.

Figure 7 shows the existing chip shape classification ranging from 1 (critical) to 8 (highly preferred) according to Stahl-Eisen-Prüfblatt 1178–1190. This Figure is used to determine the chip shape class for each specific run test on the test rig at the Institute.

Casing Milling Tests and Results

Casing Milling Using Conventional Inserts

The first test sets were performed with the conventional inserts. The casing type L80 was used for all run tests. Figure 8 shows one of the casing samples L80 before milling and after completing the milling process.

In addition to the documentation of the test results, the used insert and the produced chips for each specific test were documented and archived. For this purpose, small glass bottles and special oil (WACKER® silicone oil) were ordered and used for safe keeping and documenting the chips for each test. Figure 9 below shows the used silicone oil and the glass bottles before and after the test. A code indicating the test set operating parameters and conditions was also used and attached to each bottle; see Figure 9 (right).

In each performed individual test, only one operating parameter was varied. For instance, the rotational speed was set to specific value for example 75 rpm and the forward velocity was varied from 0.05 –0.2 mm/s, increasing the forward velocity each step 0.05 mm/s for each test. In such a case, it is ensured that only the altered parameter caused the changes observed during the test. Similarly, the tests were repeated for the rotational speeds of 110 and 175. Tens of tests were carried out during this study, whereby a few tests were not effective because the inserts were broken or strongly worn at an early stage of the milling test. Consequently, the milling process was stopped. Those ineffective test results are not presented here.

Figure 10 shows the produced chip shapes and represents the test results for the rotational speeds from 40–175 rpm and forward velocities from 0.05–0.2 mm/s (0.18–0.72 m/h). It can be noticed that lower chip shape class numbers are observed at higher rotational speed. The chip shape classes at the rotational speed of 175 rpm goes to lower class number with increasing the forward velocity values. The tests were repeated here at the rotational speed of 175 rpm for different forward velocity values in order to verify the obtained results. A similar trend was observed.

The insert wear in mass loss of the insert (g) per volume (m³) of cutting tubing (casing sample) was measured for the all run tests. Figure 11 shows the insert wear results and represents the test results for the rotational speeds from 40–175 rpm and forward velocities from 0.05–0.2 mm/s (0.18 – 0.72 m/h). The general tendency is that the insert wear increases with increasing forward velocity. In contrast, insert wear decreases relatively with increasing rotational speed.

Figure 12 shows one of the conventional inserts before milling (left) and after completing the milling process (right). It can be seen that the first three blades of the insert are worn, although the first blade section of the insert is not completely worn straight up from the bottom. This

Fig: 13 One of the conventional inserts broken during the milling test

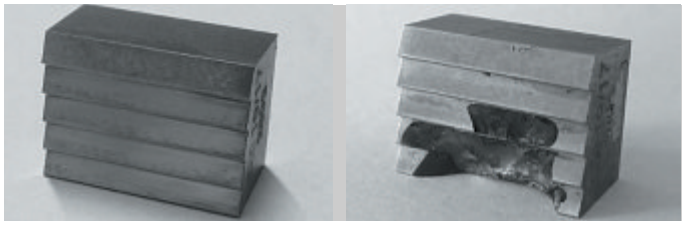

Fig. 14 One FHP-insert striped (left) before milling (right) after milling for 35 second using operation parameters (rotational speed of 110 rpm, forward velocity of 0.1 mm/s and casing type L80)

was the case for almost all the inserts. Furthermore, it was observed during the test runs and experiments that a few inserts were broken or strongly worn within a few seconds of starting the individual experiment. So a few of the tests were not effective and their test results are not considered in this article. Figure 13 shows one of the conventional inserts, which broke after only a few rotations. This effect needs further investigation to find out whether the damage is due to thermal load, material errors, etc. This needs to be studied and considered in frame of a future research project.

Casing Milling Using Ultra-Hard Material Insert (FHP-Inserts)

The second test sets were carried out by replacing the conventional inserts with the FHP-inserts keeping the test conditions similar to those used with the conventional inserts. Here also, the casing type L80 was used for all run tests. As here the number of the FHP-inserts was limited, the test conditions and operating parameters had to be selected. A total number of 6 tests were carried out, whereby four tests were ineffective because the inserts broke or were strongly worn at an early stage of the milling test. Figure 14 shows an FHP-insert striped which was worn strongly after few rotations. Consequently, the test could not proceed further.

This breaking or heavy wear of the inserts in the initial stage of the milling process needs to be studied and investigated in more detail to find out whether it is due to material errors, thermal loads, etc. It is highly recommended to include this subject in the frame of a future research project. Table 1 summarizes the successful test results of the FHP-inserts and the corresponding conventional inserts results. The insert wear is in mass loss (g) of the insert per volume (m³) of cutting tubing (casing sample). According to the available results in this study, the wear of the FHP-insert with a cobalt content of 12% is comparable to the conventional insert. However, the FHP-insert with a cobalt content of 10% seemed to be wear resistant compared to the conventional insert. In order to verify the results and to make a better comparison, it is suggested to perform further tests with the FHP-inserts using different operating parameters so that the results can be statistically confirmed and verified.

Conclusions

In the frame of this investigation, the influence of the operating parameters on the produced chip shapes and insert wear using different types of inserts (conventional and FHP-inserts) was successfully investigated and studied in the laboratory at the Institute of Drilling Engineering and Fluid Mining at the Technical University Bergakademie Freiberg. According to the obtained test results the following conclusions and findings can be made:

- A modern small-scale test rig equipped with a controller system and sensors is now available at the Institute of the Drilling Engineering and Fluid Mining to study and investigate in detail the casing milling process in boreholes. The test rig has passed through several modification and iteration processes to improve its potential. It offers the opportunity to perform casing milling processes, simulating various operating conditions. Different operating parameters, casing types and dimensions, and various insert types can be applied. Furthermore, with slight modifications, even new insert geometries can be tested. There are also possibilities to add extra sensors for better observation and understanding of the casing milling process. This modern laboratory test rig is also suited to study and investigate in detail new and innovative concepts for improving and enhancing the casing milling process.
- Tens of casing milling tests were carried out with conventional inserts using casing type L80 and applying a wide range of operating parameters (rotational speed 40–175 rpm and forward velocity 0.05–0.2 mm/s (or 0.18– 0.72 m/h)). The results show that long chips (lower chip shape class number) are formed at higher rotational speeds. The chip shape class at a rotational speed of 175 rpm moves to lower class number with increasing forward velocity values (increasing WOM).
- The general tendency of insert wear is that it increases with increasing forward velocity/WOM. It was also observed that insert wear decreases with increasing rotational speed.
- It was found that the first three blades of the inserts were worn during the tests of the conventional inserts, although the first blade section of the insert was not completely worn straight up from the bottom. This was the case for almost all the inserts tested. In addition, it was observed that some inserts were broken or heavily worn just at the beginning of individual experiments. The effect may be due to thermal loads or material errors. It is recommended to investigate the reason behind initial breakage or heavy wear of the inserts in a future project.
- Several casing milling tests with new ultra-hard material inserts (FHP-inserts) were carried out under similar conditions and operating parameters to those used for the conventional inserts. A few tests were ineffective due to breaking or severe wear of the inserts at an early stage of the test. The wear of the FHP-insert with a cobalt content of 12% was comparable to that using conventional inserts under similar conditions. However, the FHP-insert with a cobalt content of 10% seemed to be wear resistant compared to the conventional insert under similar conditions. However due to the limited number of successful FHP-insert tests, it is recommended to carry out further tests in order to statistically confirm these results.
- The old driller rule saying “more WOM

Tab. 1 Test plan and executed tests in frame this project period (Cobalt content * 12% and ** 10%)

Forward velocity (m/h)	Rotational speed (rpm)	FHP insert	Wear (g/m³)	Conventional insert	Wear (g/m³)
0.18	110	Striped / Cobalt content 12%	3713	Striped	3280
0.36	110	Striped / Cobalt content 10%	11,572	Striped	14,925

and higher rotational speed" does not hold universally. On the contrary, the successful tests performed on the laboratory test rig showed that there is an optimum parameter combination between WOM and rotational speed, which minimizes milling tool wear and produces favorable chip shapes. It is highly recommended to run further tests in fine steps to statistically verify and safely quantify optimum operation parameters, and to prove the findings. The findings are to be used for developing a milling guideline for field application. This work should also be supported by field tests for correlation and verification purposes. The investigation of the influence of further insert material types and geometries on the chip shape and insert wear should be continued by producing and testing advanced prototype inserts on the laboratory test rig.

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