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Viet Nam, Russia boost co-operation, EXPANDING OIL AND GAS EXPLORATION AND PRODUCTION AREAS **Editor-in-chief** Dr. Sc. Phung Dinh Thuc

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Cover photo: Prime Minister Nguyen Tan Dung and Petrovietnam's leaders visited Vietsovpetro exhibition corner at Zarubezhneft headquarters, Russia. Photo: Nguyen Dung







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Viet Nam, Russia boost co-operation, EXPANDING OIL AND GAS EXPLORATION AND PRODUCTION AREAS

In the framework of his official visit to Russia from 12 to 15 May 2013, Prime Minister Nguyen Tan Dung held talks with President Vladimir Putin and Prime Minister Dmitry Medvedev on many important issues to develop the comprehensive strategic partnership, promoting co-operation in the mainstay fields of bilateral relations, including oil and gas fields. Leaders of the two countries pledged to continue creating favourable conditions for the operation of the two sides' oil and gas businesses in each country, and encourage the establishment of new joint ventures to expand oil and gas exploration and production areas in Viet Nam, Russia and third countries.



Prime Minister Nguyen Tan Dung witnessed the signing of the memorandum of understanding (MOU) between Petrovietnam and Rosneft. Photo: VNA

Encouraging the establishment of new joint ventures

Prime Minister Nguyen Tan Dung on 14 May 2013 held talks with Prime Minister Dmitry Medvedev in Moscow. In the spirit of openness and mutual trust and understanding, the two Prime Ministers reaffirmed their determination to implement the high-level agreements on further strengthening the comprehensive strategic partnership between Viet Nam and Russia, as well as boosting co-ordination in the international arena, contributing to peace, stability and prosperity in the Asia - Pacific region and in the world.

Regarding economic co-operation, Viet Nam and Russia have seen much progress with strategic projects in the fields of trade, energy, oil and gas, nuclear power and mining. In the energy sector, the two Prime Ministers emphasised the efficient operation of businesses and oil and gas joint venture companies of the two countries in recent years, and pledged to continue creating favourable conditions for the operation of the two sides' oil and gas businesses in each country, as well as encourage the establishment of new joint ventures to expand oil and gas exploration and production areas in Viet Nam, Russia and third countries.

Prime Minister Dmitry Medvedev stressed that Russia attaches special importance to promoting co-operation with Viet Nam, and confirmed that he will do his utmost to work with Viet Nam to further deepen the two countries' relations. The Russian Prime Minister hoped the two sides would soon sign agreements to comprehensively foster economic ties between the two countries and agree on a priority list of investments, including the energy sector.

The Prime Ministers of Viet Nam and Russia confirmed that co-operation will continue to be strengthened in the fields of science and technology as well as education and training, committed to bring bilateral relations in these fields to a strategic importance level, and agreed to create the conditions and mechanisms of co-operation for the agencies concerned of the two countries to conduct scientific research and technology transfer in the framework of joint projects and programmes.



Prime Minister Nguyen Tan Dung and Prime Minister Dmitry Medvedev witnessed the signing of MOU between Petrovietnam and Zarubezhneft. Photo: VNA

After the talks, Prime Minister Nguyen Tan Dung and Prime Minister Dmitry Medvedev witnessed the signing of important documents between the two countries, including the memoranda of understanding (MOU) between Petrovietnam and Zarubezhneft, Gazprom, and Gazprom Neft (Gazprom's subsidiary).

Accordingly, Petrovietnam and Zarubezhneft will intensify meetings and exchanges in the near future to set out measures to increase oil production of the Vietsovpetro and Rusvietpetro joint ventures, as well as look for joint projects in Viet Nam, Russia and third countries. Petrovietnam requested Zarubezhneft to increase investment in equipment for oil and gas operations, expand Rusvietpetro's area of activities to other fields in the Nenets area, and push up the establishment of a new joint venture operating in the Barents and Caspian seas, offshore Russia. At the same time, Petrovietnam and Zarubezhneft also signed a memorandum of understanding to establish a drilling joint venture supplying services to oil and gas projects in Russia, Viet Nam and third countries. With Gazprom, Petrovietnam signed a memorandum of understanding on the production and use of gas as motor fuel in Viet Nam. With the letter of intent signed with Petrovietnam, Gazprom Neft is expected to participate in oil refinery and petrochemical projects in Viet Nam, including participation in the purchase of shares of capital projects to upgrade and expand the Dung Quat Refinery. The documents and agreements signed between Petrovietnam and Russia's oil and gas companies have created a solid foundation for promoting and expanding oil and gas co-operation

between the two countries' enterprises and bringing it to a new height.

Energy co-operation as a top priority

Prime Minister Nguyen Tan Dung met with President of Russia Vladimir Putin in Sochi on 15 May. In a friendly and trusting atmosphere of mutual understanding, Prime Minister Nguyen Tan Dung informed President Vladimir Putin of the outcomes of the talks with his Russian counterpart Dmitry Medvedev, and exchanged views on the actual situation and orientations for promoting bilateral co-operation in order to develop the strategic partnership in a practical and effective manner.

Prime Minister Nguyen Tan Dung also informed President Vladimir Putin of the East Sea situation and pledged to create all possible favourable conditions for Russian oil and gas companies to expand operations in the continental shelf and offshore Viet Nam in line with international law and the United Nations Convention on the Law of the Sea (UNCLOS). Prime Minister Nguyen Tan Dung and President Vladimir Putin stressed that energy co-operation was among the top priorities of cooperation between the two nations. The Russian side will continue oil and gas exploitation activities in Viet Nam's continental shelf and encourage the two countries' joint ventures to expand co-operation in Russia.

After the meeting, Prime Minister Nguyen Tan Dung witnessed the signing of a new oil and gas contract between Petrovietnam and Rosneft and a memorandum of understanding (MOU) between Petrovietnam and Rosneft to strengthen co-operation between the two



Prime Minister Nguyen Tan Dung and Prime Minister Dmitry Medvedev witnessed the signing of MOU between Petrovietnam and Gazprom. Photo: VNA

and efficiency of Petrovietnam and Zarubezhneft in oil and gas exploration and production in the Vietsovpetro and Rusvietpetro joint ventures, as well as the expansion of the scope of cooperation to servicing the oil and gas sector through the establishment of new joint ventures providing oil and gas drilling services. The Government of Viet Nam has always created favourable conditions, supported and encouraged the activities of investors, including companies operating in the oil and gas sector, in accordance with the laws of Viet Nam and international practices and will continue to do so to ensure their legal rights in Viet Nam and bring

oil and gas companies. The MOU - signed by Rosneft's Chairman Igor Sechin and Petrovietnam's Chairman DSc. Phung Dinh Thuc - acknowledges both parties' intention to expand their co-operation in both the upstream and downstream segments of the oil and gas industry in Viet Nam, Russia and third countries. Prime Minister Nguyen Tan Dung expressed his confidence that with the efforts to find opportunities for expansion of co-operation between Petrovietnam and Rosneft in oil and gas prospecting, exploration and production projects in Viet Nam and Russia together with Rosneft's long-term supply of crude oil for Viet Nam, the two companies will have an increasingly close and effective co-operation.

After completing the acquisition of TNK-BP in March 2013, Rosneft became the world's largest publicly traded oil and gas company by hydrocarbon reserves and production with its daily production reaching 4.6 million barrels of oil equivalent per day. Rosneft has entered the Vietnam market through TNK Vietnam, which holds 35% equity ownership of Block 06.1 and 32,67% shares in the Nam Con Son Pipeline.

As part of the working programme, Prime Minister Nguyen Tan Dung, the senior-level delegation of the Government of Viet Nam, DSc. Phung Dinh Thuc, Chairman of Petrovietnam, and Dr. Do Van Hau, President & CEO of Petrovietnam, visited Zarubezneft and had a meeting with Mr. Sergey Ivanovich Kudryashov, General Director of Zarubezhneft. This important and traditional partner is the longest-standing Russian partner in the field of oil and gas prospecting, exploration and production in Viet Nam. The Prime Minister appreciated the co-operation practical benefits to the investors as well as to Viet Nam on the basis of common interest.

The Viet Nam - Russia Joint Communiqué confirmed that the two sides spoke highly of the performance of the oil and gas companies and joint ventures of the two countries such as Petrovietnam, Gazprom, Zarubezhneft, Rosneft, Lukoil Overseas, Vietsovpetro, Rusvietpetro, Gazpromviet, and Vietgazprom, and agreed to continue facilitating their operation as well as to encourage the establishment of new joint ventures to expand oil and gas exploration and production areas in Viet Nam, Russia and third countries. The two sides confirmed to further strengthen co-operation in the field of oil and gas exploration and production on the continental shelf of Viet Nam in accordance with international law, particularly the United Nations Convention on the Law of the Sea (1982).

The official visit to Russia of Prime Minister Nguyen Tan Dung has made important contributions to advancing the Viet Nam - Russia comprehensive strategic partnership, in which favourable conditions are created for the development of the oil and gas sector. The active deployment of co-operation activities once again confirms that co-operation in the energy field in general and in the oil and gas sector in particular has been playing a strategic role, contributing to boosting economic co-operation, trade and investment between the two countries as well as strengthening the special traditional ties between the two nations and peoples of Viet Nam and Russia.

Nguyen Hoang

VIETNAM PETROLEUM INSTITUTE WORKS TOWARDS A STRONG "VPI TRADEMARK"

Over 35 years of development, the Vietnam Petroleum Institute has created its clear imprint by providing valuable consultancy for the whole value chain of the country's petroleum industry. It is one of the few institutions whichhavesuccessfullytransformedthe operational model to an autonomous and self-managing public scientific and technological institution in accordance with Decree no. 115/2005/ND-CP. This important move has created an essential transformation, linking scientific research and technological development with production, business and human resource training, boosting technological application and transfer, and contributing to enhancing the scientific and technological strength of the oil and gas sector.



Dr. Do Van Hau, President and CEO of Petrovietnam, and Dr. Phan Ngoc Trung, General Director of VPI, chaired the Science and Technology Conference. Photo: Le Van

The Intellect of Petrovietnam: Integration and Sustainable Development

The Vietnam Petroleum Institute (VPI) hosted a Science and Technology Conference on the topic "The Intellect of Petrovietnam - Integration and Sustainable Development" on 22 and 23 May 2013 on the occasion of celebrating its 35th Anniversary of foundation. The Conference focused on discussion of practical scientific issues currently facing the petroleum sector of Vietnam in its development, which were classified into the following thematic groups: oil and gas exploration and production - innovative thinking for success; field management and production: efficiency and safety; improving efficiency of refineries and petrochemical plants; oil and gas safety and environment protection; and reform of management systems for sustainable development. This was also an opportunity for local and foreign scientists and managers to meet and exchange experiences, especially new technologies in oil and gas exploration and production.

After 35 years of development, the VPI has become the leading scientific and technological institution of Viet

Nam's oil and gas industry, with several fields of activity reaching regional level. It is now capable of carrying out R&D activities and providing scientific and technological services to the whole value chain of the petroleum industry. VPI has conducted valuable studies of the country's hydrocarbon potential, which serve as the basis for the Government to direct the orientations, policies and strategies for development of the oil and gas industry. VPI also plays the role of an adviser to Petrovietnam's leaders in the making of important decisions and the definition of specific plans to enhance the performance efficiency and the quality of growth.

In the field of oil and gas prospecting, exploration and production alone, VPI has presided over and participated in thousands of scientific and technological research projects/assignments of national, ministerial and sectoral levels as well as delivered thousands of scientific research contracts. At present, VPI is the country's leading institution in conducting researches to determine the geological structures, assessing the hydrocarbon potential and reserves of sedimentary basins in land and on the continental shelf of Viet Nam as well as abroad, quantifying hydrocarbon reserves, locating new drilling wells, developing and applying solutions for production operation, enhanced oil recovery, and safe and efficient field management.

Notably, the "Assessment of hydrocarbon potential of Viet Nam's territorial waters and continental shelf" project presided over and conducted by VPI (under the Master Plan for "Basic survey and integrated management of marine resources until 2010 and vision to 2020") has been assessed as one of the projects which have made new and valuable contributions to petroleum geology. According to Dr. Phan Ngoc Trung, General Director of VPI, from the basic survey studies conducted, the institute has developed a reliable and constantlyupdating scientific database of hydrocarbon potential and reserves in the territorial waters and the continental shelf of Viet Nam to facilitate the formulation of policies and development of strategies for oil and gas prospecting, exploration and production; and proposed measures for the State to manage and rationally exploit the marine resources and environment in a scientific, effective and efficient manner, satisfying the requirements for sustainable economic development and contributing to safeguarding the national sovereignty and security.

Especially, from 2008, in response to the requirements of the new context, especially to the demand for a breakthrough in scientific and technological management to liberate the creative potential and prepare for the future when a scientific and technological market really takes shape, VPI has bravely transformed its operational model into an autonomous and self-managing public scientific and technological institution in accordance with the Government's Decree No. 115/2005/ND-CP. This important move has created an essential transformation, linking scientific research and technological development with production, business and human resource training, boosting technological application and transfer, and contributing to enhancing the scientific and technological strength of the oil and gas sector.

However, as Decree No. 115's organisation model of scientific research was totally new in Viet Nam, it has caused certain pressures on VPI's revenues and works as well as affected the execution of its basic, long-term and strategic research tasks. In spite of this, the institute has boldly changed its mindset, developed and undertook numerous drastic measures, on the basis of the learningwhile-doing and changing-and-adjusting approaches to liberate and promote its creative strength for the continued development of Viet Nam's petroleum science and technology.

Working towards a strong "VPI trademark"

For the new period, the Vietnam Oil and Gas Group (Petrovietnam) has set the objectives to accelerate its development in a sustainable way in 5 business areas: oil and gas exploration and production, oil refinery and petrochemistry, gas industry, electric power industry, and

<image>

General Director of Zarubezhneft in a visit to VPI - EPC. Photo: Nhu Trang

petroleum technical services. On that basis, Petrovietnam has set science and technology among the 3 breakthrough measures for the sector development, besides human resource and management. At the same time, Petrovietnam continues to further invest in science and technology and improve the guality, efficiency and effectiveness of scientific and technological research projects/assignments in order to create the foundation and impetus for a sustainable and in-depth development of Petrovietnam's main production and business lines, with the primary objective of "enhancing the quality of growth".



VPI's leaders visited laboratories of GEUS. Photo: VPI

During the 2008 - 2012 period, VPI has conducted 328 research projects/assignments and 190 scientific and technological service contracts on schedule and with good quality, recording a total revenue of VND 1,574 billion. In 2013, VPI will strengthen basic surveys and studies, pro-actively propose orientations for new long-term and medium-term studies, and strive to gain a revenue of VND 407 billion from its research activities and scientific and technological services.

Speaking at the Conference, Dr. Do Van Hau, President and CEO of Petrovietnam, highly appreciated the achievements made by VPI and asserted that the institute plays a central role in delivering the scientific and technological breakthrough. He requested VPI to focus, in the coming period, on implementing a number of urgent tasks for the development of the industry: continue to conduct the overall survey of sedimentary basins and new potential areas and objects in Viet Nam's waters, especially deep water and offshore areas; conduct specific research programmes for field development and production, reserve increase, enhanced oil recovery, heavy oil production and processing as well as exploration and development of unconventional hydrocarbons (coal bed methane, gas hydrates, shale gas, etc), specific studies for development of the power sector, oil and gas processing and technical services; and contribute to enhancing the performance and efficiency of Petrovietnam's projects and plants.

These have become increasingly urgent demands as science and technology must go one step in advance, rationally combining applied research and basic research to efficiently facilitate the production and business activities of Petrovietnam. Only then can it be possible to ensure the sustainability and viability of the development strategy, create the breakthroughs to enhance the competitiveness, and narrow the development gap with major oil and gas groups in the region and in the world.

future Regarding the development strategy, Dr. Phan Ngoc Trung said the Vietnam Petroleum Institute will work towards a strong "VPI trademark" through focus on scientific and technological research and development. In particular, VPI needs to successfully improve the quality and quantity of strategic projects/assignments to facilitate Petrovietnam's operations both at home and abroad; provide consultancy for and appraise investment projects, co-ordinate

the implementation of R&D projects/contracts ordered by Petrovietnam and its subsidiaries. At the same time, VPI needs to assemble and train a contingent of leading scientists, as well as concentrate resources on completing its restructuring process, in order to build VPI into a full-fledged specialised and comprehensive Petroleum Academy, harmoniously combining 3 functions of research, application and training.

With a tradition of 35 years of development and the pride of the Winner of the Labour Hero Title and the Independent Order Third Class, the complement of managers and scientists of the Vietnam Petroleum Institute will effectively mobilise all resources, bring together the Intellect of Petrovietnam, and improve their research capacity to tackle the practical problems emerging, thus making important contribution to the delivery of a rapid, vigorous and sustainable development of Petrovietnam.



Petrovietnam Exploration Production Corporation (PVEP) is a pivotal member of the Vietnam National Oil and Gas Group and has made strong progress on the road to integration. For its development path ahead, PVEP will place great emphasis on efficiency and professionalism in its efforts to become a competitive company both within the region and world-wide.

Building on tradition

On 20 May 2013, PVEP celebrated the 25th Anniversary of its Traditional Day in Hanoi. On the basis of the background and experience inherited from the preceding generations of the petroleum industry and its two precursors – the Petrovietnam Investment and Development Company (PIDC) and the Petrovietnam Exploration Production Company (the old PVEP), the Corporation has successfully achieved important targets in its very first year of operations, including completion of its organisational and management structures, building up development strategies, systematising and developing a regulatory system to govern and to enhance its operations - especially in the fields of exploration and production - both domestically and internationally.

In recent years, PVEP has successfully completed its business and production tasks, contributing to ensuring national energy security, and being a pioneer in international economic integration. From a beginning when it only monitored the implementation of oil and gas contracts, PVEP has grown significantly with enhanced productivity and increased scope and scale of operations. It has recorded great increases in reserves and production in several years, maintaining a high and steady pace of growth in revenue and state budget contribution, actively contributing to the development of Petrovietnam and the country's economy. So far, PVEP has produced over 40 million tons of crude oil and condensate, 36.5 billion m³ of gas, and increased reserves to 273 million tons of oil equivalent. The corporation has successfully transformed its organisation management to the independent accounting model. PVEP's total assets increased from VND30,723 billion in 2007 to VND114,115 billion in 2012. Its managerial and technical personnel have really matured, mastered science and technology, and gradually risen to fully take charge of the exploration and production projects both at home and abroad.



Honouring the different generations of PVEP's leaders. Photo: PVEP

Actively implementing new projects

From the beginning of 2013, PVEP has been screening 37 opportunities, 32 in Viet Nam and 5 internationally. At the end of March, PVEP entered into a PSC contract for Block 42 in the Phu Quoc Basin. It plans to sign into other ventures such as Block 11-2/11 in the Nam Con Son basin and Block 125-126 in the Phu Khanh basin. Decisions are being made regarding whether it would take part in some new blocks in the Cuu Long, Phu Khanh and Nam Con Son basins and some tendering rounds in Myanmar. Paralleled with searching for new ventures, PVEP is finding ways to farm out some of its projects in order to minimise risks.

In the first quarter of 2013, exploration has been carried out on schedule; two overseas projects of 2D seismic acquisition were rendered in an area of 305km and 3D seismic acquisition of 760km² was completed. Four wells were appraised, resulting in an increase in reserves of 0.25 million tons of oil equivalent. PVEP will keep on track with its seismic acquisition and exploration plans in the second quarter of 2013, aiming at a net reserve increase for PVEP of 3.84 million tons of oil equivalent. On 10 May 2013, the Chairman of Petrovietnam signed Decision No. 917/QD-DKVN recognising 20 May as the Traditional Day of PVEP. On 20 May 1988, Petrovietnam II Company (PV-II) - the first precursor of PVEP - was established. A few months later, Petrovietnam I Company (PV-I) was set up by the Vietnam General Administration of Oil and Gas. The main tasks of the two companies were to monitor the implementation of oil and gas prospecting, exploration and production contracts which Petrovietnam has signed with foreign oil companies, step by step develop exploration and production activities in the country and then extend investment abroad, opening up great prospects in the process of finding and exploiting the natural resources of the country.

On 20 March 1993, PV-I was converted into the Petrovietnam Production Sharing Contract Supervising Company (PVSC), which was tasked with monitoring oil and gas contracts, whilst PV-II became the Petrovietnam Exploration Production Company (the old PVEP) with the responsibility to monitor a number of oil and gas contracts in the south. On 14 February 2000, PVSC was renamed Petrovietnam Investment and Development Company (PIDC) and commenced investment operations abroad.

On 4 May 2007, Petrovietnam decided to establish the Petrovietnam Exploration Production Corporation (PVEP) on the basis of the two most important companies, the Petrovietnam Investment and Development Company (PIDC) and the old Petrovietnam Exploration Production Company (the old PVEP). This is a strategic move by Petrovietnam to focus resources in the core areas of activity, and enhance the autonomy and competitiveness of PVEP to develop it into an international oil and gas company which operates both domestically and abroad.

Thanks to efforts made by its staff, joint-operating companies, partners and contractors, PVEP has successfully reached all its production targets. The first quarter's total production amounted to 1.26 million tons, thus achieving 109% of the plan with a 9% increase against the same period last year. Of this figure, oil accounted for 0.9 million tons, 102% of the plan with a 4% increase. Gas accounted for 358 million m³, 119% of the plan and a 22% increase respectively. In the second quarter, PVEP is poised to bring in 1.13 million tons of oil equivalent, of which oil and condensate account for 0.82 million tons and gas 300 million m³. Up to the end of the first guarter, total development fields stood at 12 wells, of which 9 have completed development work and are on budget and on schedule. This helps to increase PVEP's daily production to 75.000 barrels of oil. The remaining 3 wells are under development both in Viet Nam and overseas. PVEP continues with completion of 2 development wells in Block 15-2/1.

Thanks to completing its production plans and to stable oil prices, PVEP has exceeded its financial targets. Revenue for the first quarter of 2013 is estimated at VND 15,000 billion, equivalent to 123% and 31% of the quarter and yearly plans respectively. The budget contribution is set at VND 4,426 billion. PVEP is expected to reach revenue totaling VND 11,700 billion with a budget contribution of VND 3,460 billion in the next quarter.

Ensuring national energy security

PVEP's development strategy towards 2015 and its orientation towards 2025, as part of the master plan for the whole industry, have been approved by Petrovietnam and implemented based on the following outlooks and principles: to mobilise all resources at full capacity; to court support from competent authorities; to promote co-operation and co-ordination in order to speed up its development; to push up investment in exploration and production both in Viet Nam and overseas so as to secure energy reserves for sustainable development and increase its production outputs; to increase financial contributions to the State Budget; and to ensure perfect harmony between its economic interests and the development goals of Petrovietnam in particular and the nation in general.

Domestic exploration activities are challenging as hydrocarbon potential now mainly lies in marginal and deep water areas. For development and production projects, the cost control issue has been strictly managed while the implementation pace is kept steady. Foreign investment operations come, of course, with risks in terms of security, politics and operational conditions, not to mention harsh competition from international companies and difficulties in arranging capital flow. Therefore, in addition to strengthening its capabilities in project management and operations, PVEP has been taking comprehensive measures to ensure the efficiency of all investment



The first flow of crude oil from Wellhead Platform H4 of Te Giac Trang field. Photo: PVEP

ventures, including: reviewing and restructuring its investment portfolio, diversifying its investment instruments, tightening its control over project progress and taking more initiatives in financing for its projects. In facing such challenges, PVEP has put all their resources to ensure first oil production schedules in 2013 are met in their focal projects like Blocks 433a & 416b (Algeria), Junin 2 (Venezuela) and other important development and production ventures.

At present, PVEP has over 20 projects/fields in the development and production phase locally and internationally, of which 8 began production in 2013. Resources have been concentrated on development projects with first oil production planned in 2013. This will contribute greatly to PVEP's overall production figures, once the plans are realised. PVEP is now participating in 61 petroleum projects (41 in Viet Nam and 20 overseas) and 5 basic survey projects. Among these, PVEP is operating 19 projects, jointly operating 15 and has an interest in 27.

for production development As projects in Viet Nam, PVEP continues to improve field management, the operating process and maintenance, and enhance cost examination, conditional technical review, and economic efficiency of projects. As for overseas projects, PVEP will focus on developing newly discovered oil fields to start commercial production, optimising exploration operations, reviewing costs, output, reserves and economic efficiency, anticipating risks in its investment projects, and defining orientations for specific projects. PVEP also intensively researches and selectively applies new advanced technologies to oil and gas exploration. In particular, PVEP will concentrate all its resources to enhance the technical qualifications of its personnel in the fields of geology, engineering and drilling technology, production development, and oil and gas project operation and management.

The success achieved has been an important foundation for the corporation to release its Development Strategy and Plan from now till 2015 and orientation to 2025 and to become a professional international oil and gas firm. PVEP is determined to overcome challenges to build the corporation into a leading oil and gas company with well-established position and brand name in the region and in the world, contributing to national energy security as well as protecting national sovereignty.

PVEP HOSTS 2013 TECHNICAL FORUM "CHALLENGING RESERVOIRS IN VIETNAM"



Dr. Hoang Ngoc Dang, PVEP's Chairman, congratulated excellent presenters at the Technical Forum.

On 29 and 30 May 2013, Petrovietnam Exploration Production Corporation (PVEP) hosted the 2013 Technical Forum "Challenging Reservoirs in Viet Nam" in Ho Chi Minh City with over 350 participants. According to Dr. Hoang Ngoc Dang, Chairman of PVEP, the objective of the forum is "to exchange technical knowledge, experiences as well as to share the difficulties and lessons learned" with a view to "contributing positively to the efficiency of oil and gas exploration and production in the continental shelf of Viet Nam".

In recent years, Petrovietnam has accelerated exploration and production activities both at home and abroad with a view to increasing hydrocarbon reserves and production output. Petrovietnam has planned to increase reserves to 35 - 40 million tons of oil equivalent and produce 16 million tons of crude oil and 9.2 million m³ of gas in 2013. However, exploration and production activities in Viet Nam are becoming more challenging as production output in conventional fields are declining whilst the conditions for deploying new projects are increasingly difficult, especially in small, marginal fields and in deep water and offshore areas. The organisation of this forum with the theme "Challenging Reservoirs in Viet Nam" by PVEP therefore not only responded to a very practical need from stakeholders concerned in the upstream operation of Petrovietnam but also attracted special interest of foreign petroleum companies and contractors.

During the 2 days of the forum, 31 interesting presentations from amongst the 54 technical papers sent to the forum were delivered by the authors, focusing on the fields of exploration, development and production. Experts from local and foreign petroleum companies discussed difficulties and challenges that they have met with when conducting exploration and appraisal operations or making choices on field development and production plans. They also shared solutions to minimise risks and to overcome the difficulties and challenges.

The forum was hailed by local and international experts and managers attending its plenary meeting and 6 sessions as a very successful event, creating a friendly and professional environment for all stakeholders in the oil and gas industry to meet and discuss in an efficient way. The enthusiastic participation and contribution of companies and experts across the oil and gas sector in this event has also encouraged PVEP to schedule the next Technical Forum in 2014 with the topic "Marginal fields, challenges and solutions".

Xuan Son

Manh Hoa



ASPIRES TO CONQUER THE OCEAN

20 years of a strong brand

On May 29, in Ho Chi Minh city, PTSC celebrated 20 years of development and received the Labour Medal First Class. PTSC started with nearly 850 employees, total assets of less than VND 100 billion, revenues of VND180 billion, and profits of VND 11 billion. After 20 years, its revenue has increased over 135 times, profits have jumped 120 fold and personnel expanded by 8 times. At present, PTSC has over 23 affiliates, 4 joint ventures in Singapore, Malaysia, and overseas branches in Cuba, Venezuela, Malaysia and elsewhere with a total staff complement of more than 10,000 people who have high levels of professional skill. These very impressive figures indicate PTSC's strong growth in both quantity and quality of capability and skills.

After 20 years of construction and development, Petrovietnam Technical Services Corporation (PTSC) has now become a leading provider of oil and gas technical services in Viet Nam and gradually asserted its position and name on the international market. The corporation has invested in massive, synchronous infrastructure and equipment systems; recruited and trained managerial and technical personnel to assume most managerial and technical positions in the oil and gas industry; and proved sufficient capacity to operate as an EPCI contractor for oil and gas projects as well as other civil and industrial projects.

PTSC is a pioneer supplier of services related to oil and gas exploration and exploitation in Viet Nam. The corporation actively explores and develops new types of services. Whenever the market requires either highlevel technical services or normal technical services, PTSC always does its best to mobilise internal and external resources to supply the best services for oil and gas contractors, thus continuing to inherit, build and develop a new and separate service to diversify its range of services and gradually expand its operations. Currently, PTSC confidently asserts its strengths in six primary categories of services: marine service; supply base, ports and logistics services; FPSO/FSO supply, operation and maintenance; marine mechanical



PTSC received the Labor Medal First Class. Photo: PTSC

services; operation and maintenance; seismic surveys and ROV services.

PTSC is the first and only Vietnamese company to own, operate and exploit a fleet of multi-service ships. PTSC is also the only one to possess port base systems and logistics services for the oil and gas industry stretching throughout the nation. With total area up to 150ha including Vung Tau Supply Base (81.5ha), Phu My Port (26.5ha), Dung Quat Port (15 ha), Hon La - Quang Binh Port (8.8ha), Dinh Vu Port (13.9ha), and Nghi Son - Thanh Hoa Port (9.8ha), the company meets all requirements for open storage, bonded warehouse, office, fabrication workshop, and logistics services for oil companies operating in Viet Nam. PTSC is currently concentrating on completing the investment for the expansion and development of its deepwater supply base system on a national scale to meet all service demands for oil and gas exploration and production in Viet Nam, as well as serve other economic fields.

PTSC is the only company in Viet Nam to possess and operate floating production storage and offloading storage (FPSO/FSO). This service is complex to manage since FSO/FPSO operation and commissioning techniques require a supply of dedicated and experienced manpower and very strict safety requirements. Besides, PTSC is also the only Vietnamese company to be able to design, procure, fabricate, hook up and commission oil and gas rigs. Starting with this service in 2002, PTSC has proved that it is a fully capable contractor. The firm has successfully carried out 40 projects on schedule, including the Su Tu Trang project, Bien Dong 1 project, Rong Doi project, Su Tu Trang/Su Tu Den projects and Thang Long - Dong Do projects. At present, PTSC is fully qualified to take on the role of general contractor for major oil and gas projects.

In the past 20 years, PTSC has very actively cooperated with the relevant ministries and branches in the implementation of State-assigned tasks on issues related to borders, seawaters, islands and sovereignty protection in the East Sea. The corporation always urges oil and gas contractors to carry out baseline surveys acording to commitments.

PTSC has collected explosion samples on over 92,000km of 2D seismic tests and over 23,000km² of 3D seismic tests in the country, and on 6,800km of 2D seismic tests and over 2,000km² of 3D seismic tests. Particularly during 2012, contractors have collected explosion samples on 14,000km of 2D seismic tests and over 15,000km² of 3D seismic tests. The operation of the Binh Minh 02 vessel is an important step towards developing a range of high-tech services in Viet Nam to serve oil and gas baseline surveys and reserve assessments as well as in the search for oil. Although PTSC has supplied this service for only a couple of years, the corporation has already secured the No.1 position for this service provision in Viet Nam.

Focused investment in seismic survey, geological, underground and ROV (remotely operated vehicle) survey services has helped PTSC assert its leading position and capacity in Viet Nam. Together with key service development, PTSC also effectively maintains and develops a variety of services such as manpower supply, ship agent and hotels whilst creating stable employment for its staff.

Development strategy

PTSC has continuously invested in technology and successfully produced many modern large-scaled oil platforms, making an effective contribution to developing the marine economy. PTSC has also entered into joint ventures, coordinated and gradually acquired technologies in combination with developing and applying advanced management models in the world, such as ISM Code, ISO 9001 - 2000, OSHAS 14001 and ISPS; applied information technology to management and administration; enhanced the role and responsibility of staff in managing and directing production, and maximised the creativity and working capacity of its employees. Besides, PTSC has intensively focused on developing specialised technical services to generate high economic efficiency. This has turned PTSC from a small supplier of simple low value-added services to a leading technical service corporation in Viet Nam with gradual business expansion throughout the region and the world.

As a leading oil and gas technical service supplier in Viet Nam, PTSC not only focuses on building up on its own services, but also works closely with other units in the industry, and supports other units to use its services to the best for mutual development. PTSC has recently undergone an entire restructuring to concentrate its resources on the core services and continue building and developing the services it created in its very first days. PTSC has created a complete scientific system of technical services for oil and gas exploration and production in Viet Nam, which has contributed positively to Viet Nam's oil and gas production in recent years.

In addition to occupying and maintaining the domestic market, PTSC also focuses on promoting export of its services, thus becoming one of the first Vietnamese companies to bring offshore petroleum technical services to foreign countries. To date, the corporation has carried out many large overseas projects, such as fabricating an oil platform for Talisman Malaysia, providing the Binh Minh vessel for long-term operation service in Indonesia, Thailand and Russia, supplying DP2 vessel to Malaysia, and investing in FSO/FPSO in Malaysia. PTSC is a pioneer in opening branches in foreign countries such as Cuba, Venezuela and Malaysia. The corporation is capable of providing most oil and gas services, including those that require sophisticated technologies, expertise and workmanship, as well as functioning as an EPCI contractor of important oil, gas and other projects. PTSC is known amongst its partners and oil and gas contractors as a professional and highly reliable service provider offering constant service quality, safety and efficiency.

With the aim of developing rapidly, strongly and sustainably, combining economic development, environmental protection and national security and defence, taking customers' satisfaction as a lodestar for its operations, and cooperating with domestic and foreign partners, PTSC has gradually confirmed and proved its business strategy set for the period from now to 2015, with consideration towards 2025, with the overall target of building PTSC into a powerful, well-known oil and gas technical service provider in the region and in the world.

Accordingly, PTSC will focus its resources on upgrading its infrastructure and developing human resources to successfully carry out its rapid growth strategy in which the corporation will focus on the following primary



FPSO Rubby II. Photo: PTSC

services: marine services; supply base, ports and logistics services; FPSO/FSO supply, operation and maintenance services; operation and maintenance (O&M), transportation, installation, hook-up, and commissioning oil and gas project services; and ROV (remotely operated vehicle) seismic acquisition. This is the key for the corporation to live through all difficulties and to become a leading oil and gas technical service provider in Viet Nam and to gradually assert its capacity, prestige and brand name in the region and throughout the world.

Khanh Linh

PREDICTING THE QUALITY OF MIDDLE MIOCENE RESERVOIR OF SOME UNDRILLED PROSPECTS IN NORTH SONG HONG BASIN

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Summary

Song Hong basin evolution was related to the extrusion and clockwise rotation of the Indochina block, which were caused by the collision of the Indian and Eurasian Plates. The extrusion along the Red River Fault Zone, accompanied by clockwise rotation of the Indochina block, controlled the Tertiary sedimentation and deformation of the North Song Hong basin. As the deformation varied along the Red River Fault Zone, the strong uplift and erosion in Late Miocene were only recorded in the North Song Hong basin. There will be a great uncertainty if we use the relationship of porosity versus depth of drilled wells in uplifted and eroded prospects to predict that relationship for undrilled prospects of which the uplift and erosion are unknown.

A combination of seismic data and surrounding well data could help minimise the uncertainty in predicting the relationship of porosity versus depth in the undrilled prospects. This approach was presented in this paper and applied to Middle Miocene reservoir of prospects KL and DL in the North Song Hong basin.

1. Introduction

The Song Hong basin, about 600km in length, is elongate seaward of the Red River Fault Zone and developed NW-SE, NNW-SSE to the South of Hainan Island. The basin was formed in the Paleogene and Neogene Periods. The thickest Tertiary sediments at the depocenter exceed 17km in thickness [3]. In the North Song Hong basin, due to uplift and erosion, the current depth of the reservoir does not reflect what depth it was in the past.

The Song Hong basin evolution is very complex, however the authors agreed that deformation and uplift took place in the North of Song Hong basin (mainly in the Hanoi Trough and offshore Blocks 102, 103, 107 - Fig.1) from 10.5Ma to 5.2Ma [2, 3, 5]. Uplift and erosion were found in some areas to exceed 1,000m[7]. In conclusion, the uplift and erosion are strong and variable, so that prediction of the relationship of reservoir porosity versus depth is challenging.

2. Predicting reservoir quality by using seismic velocity (V,) and reference well data

Generally, the velocity (V_p) depends on the elastic modulii and density via:

Where:

- V_p is compression wave velocity;

 $Vp = \sqrt{(K+3/4\mu)/\rho}$

(1)

- K is bulk modulus;
- μ is shear modulus;
- ρ is rock density.

From the V_p equation, the elastic constants, and densities, in turn depend on the properties that the geologist or engineer uses to characterise the rock, such as porosity, fluid saturation and texture, etc. However, the main factors that affect compression velocity are as follows:

- Rock porosity;

 Rock matrix elastic properties (usually depend on compaction process, cementation process, and diagenesis);

- Formation pressure.

- A very rough rule due to Wyllie is the so-called time average relationship:

$$\frac{1}{Vbulk} = \emptyset/V_{fluid} + (1 - \emptyset)/V_{matrix}$$
(2)

Where $\boldsymbol{\phi}$ is the porosity

This is not based on any convincing theory but is approximately correct when the effective pressure is high and the rock is fully saturated[1]. From the above equation (2), assumption of V_{fluid} and V_{matrix} are background so that seismic velocity is directly related to porosity.

The methodology of using seismic velocity to predict undrilled prospect reservoir quality:

- Build the relationship of porosity versus depth of surrounding wells. From that chart, we can define the upper boundary and the lower boundary of porosity decay versus depth. By comparing the seismic velocity of undrilled prospects to that in the wells we can predict what the trend of porosity versus depth should be.

- Use the processed seismic velocities of one vin-



Fig.1. Block 103 & 107 and prospect inventory



Fig.2. Seismic survey 2D lines vintage PVEP 2011 - Processed by Fairfield Vietnam in 2011

tage to minimise unconformity of velocity due to seismic noise, manual velocity picking and different processing sequences. In this study, the seismic velocities used were from PVEP 2011 2D seismic survey and processed by Fairfield Vietnam in 2011 - Fig.2). The charts of surface seismic interval velocities and well interval velocity were built together to verify the quality of surface seismic velocity. If all velocities fit each other, we consider that the surface seismic velocities are qualified for predicting reservoir quality.

- Build the relationship of surface seismic interval velocities in the undrilled prospects and overlay the surrounding well velocities. If undrilled prospect seismic velocities are faster than the well velocities at similar depth, it is predicted that the porosity trend should be in the boundary (low reservoir quality) of the porosity versus. depth chart of wells built previously. Otherwise, if un-

drilled prospect seismic velocities are slower than well interval velocity, the high trend reservoir porosity and depth is predicted for that prospect.

3. Predicting reservoir quality of undrilled prospects in Block 103&107

Blocks 103 & 107 are located offshore North of Viet Nam (Bac Bo Gulf), in the Northwest of the Song Hong basin (Fig.1). In these blocks, besides basement high and stratigraphy play types, there are two other important play types: Oligocene traps and Miocene traps. The Oligocene traps are located in the West flank of basin (in Block 103). In that play type, the Oligocene and Miocene rocks were uplifted and Miocene formations almost entirely eroded to form a Base Pliocene regional unconformity in the North Song Hong basin during the Late Miocene inversion. The exposed Oligocene rock was overlaid by Pliocene formations. The other play type comprises Miocene traps. These traps were developed in the centre of the basin, in which the Miocene rocks were uplifted and eroded. Even though, Miocene strata were strongly eroded to the Southwest of Song Lo faults, the thick remaining Miocene rock is the main reservoir of that play type. The Miocene play type is located in the basin depocenter. The Oligocene reservoir is too deep for hydrocarbon exploration (> 4,000m).

The undrilled prospect/lead B, C were classified to the Oligocene play type and prospects DL and KL were classified to the Miocene play type. For the exploration wells in the blocks, the porosity versus depth relationship is presented in Fig.3 [4]. From that relationship, it could be seen that at the same depth the porosity is scattered in the range of 10%. Predicting the porosity of undrilled prospect actually following either upper trend or lower trend is valuable.

Before using surface seismic interval velocities and well velocities, both velocities in the drilled prospects were built in 1 chart of interval velocity (x axis) and two way times (y axis) to define the deviation of surface seismic interval velocities and true velocities from well. Fig.4 is a chart of surface seismic interval velocities of HAL and DL prospects versus true velocities from wells (103-HAL-1X and 103-DL-1X) and Fig.5 shows a chart of surface seismic interval velocities of HD prospect and true velocities from 102-HD-1X well. The charts in Figs.4 and 5 confirm that there is no deviation between surface seismic interval velocities and true velocities from wells and no adjustment is needed.

Surface seismic interval velocities in lead B and C are shown in Fig.6. The true velocities from wells 102-HD-1X and 102-CQ-1X were overlain in the same chart. We found that surface seismic interval velocities are much slower than the velocity in drilled 102-CQ-1X well, and a bit quicker than the velocity in drilled 102-HD-1X well. In combination with the chart porosity versus. depth in Fig.3, the 10% porosity of that prospect is predicted to the depth of 2,000m. That prediction may have some uncertainty due to the chart in Fig.3 being mainly for Miocene rock.



Fig.3. Log porosity versus depth of wells in the study area



Fig.4. Interval surface seismic velocities and well velocities over HAL and DL prospects



Fig.5. Interval surface seismic velocities and well velocities over HD prospect



Fig.6. Interval surface seismic velocities over B, C prospect and velocities of well 102-HD-1X, 102-CQ-1X

For prospect D, surface seismic interval velocities were built in a chart with true velocities from 103-HAL-1X well - Fig.7. From the interval velocity chart, we found that down to 2 seconds, the porosity versus depth relationship of undrilled prospect D was similar to that of 103-HAL-1X well, however below 2 seconds (~2,800m), the velocities deviated to two trends; one trend followed the 103-HAL-1X velocity and the other trend a slower velocity. It means that the reservoir quality in prospect D is predicted to be similar or a bit better than 103-HAL-1X.

KL prospect is a very large four-way closure (over 50km²) in Block 107. That prospect is classified to the Miocene play type. Actually, KL prospect is not located in the Miocene Inversion southwest of Song Lo Fault, rather it is located in the northeast of Song Lo Fault, where the inversion and erosion were very little. The reservoir quality of KL prospect was considered uncertain due to a depth of almost below 3,000m. All the wells drilled in the Miocene inversion play type in Blocks 103 & 107 show that reservoir quality below 3,000m is bad. To predict how reservoir quality of KL prospect compares with surrounding drilled wells, we built a chart of surface seismic interval velocity of that prospect and 103-DL-1X well interval velocity - Fig.8 (the well 103-DL-1X was chosen because DL prospect was the least uplifted and eroded prospect in the area). The chart shows that seismic velocity in KL prospect is much slower than velocity in 103-DL-1X well. That result allows us to predict that the reservoir quality in KL prospect should be better than that of DL prospect at the same depth (at the depth ~3,200m in the 103-DL-1X reservoir quality is fair, average porosity ~11% and MDT gas sample was collected). From the porosity versus depth chart in Fig.3, the porosity of KL prospect is predicted to follow the high porosity trend (prospective trend - due to slower seismic velocity in comparison with well's reference), which means that the 10% porosity would be preserved at least to ~3,500m, and more optimistically up to 4,000m. The reservoirs in KL prospect of Middle Miocene age or younger are also indicated as higher quality reservoirs.

4. Conclusions and possibility of extending study

Theoretically, there is no convincing reason that seismic velocity is only related to porosity, rather the matrix and pore pressure are affected factors as well.

In the above-mentioned method to predict reservoir quality of undrilled prospects, the assumption that matrix and pressure are homogeneous may let in some uncertainty. If we have knowledge of the depositional environment with results of seismic stratigraphy to support prediction, it may be more helpful.

Abnormal pore pressure is a factor making seismic velocity slower and may affect the prediction, however the abnormal pore pressure helps to preserve porosity.

The method was applied only for clastic sections. In the case of carbonates we do not have any conclusion. For clastics, to reduce uncertainty of the matrix, it should be better if the whole section was divided to syn-rift and post-rift sequences.

More well data from nearby undrilled prospects with the same tectonic regime would be more helpful for reservoir quality prediction.

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Hac Long platform. Photo: PVEP

CORRELATION BETWEEN FAULTS ORIENTATIONS AND HYDROCARBON RESERVOIRS IN THE EAST SEA

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Summary

The East Sea is a large area complicated by a variety of fault systems. There are many differences in the depth, orientation and dip angle of the faults. In the Cenozoic sedimentary basins, most of the faults are determined by using seismic data. Otherwise, wherever seismic data is sparse or in the Pre-Cenozoic basement, the faults are frequently determined by interpreting gravity data.

In this paper, a method of orientation analysis of faults systems to define the major trends of geological structures as well as estimate the correlation between fault orientations and hydrocarbon reservoirs in the East Sea has been carried out. The method has indicated the reliability of using faults systems for discovering and delineating areas with hydrocarbon potential. It can be said that, for particular areas, the existence of the hydrocarbon reservoirs is always consistent with the respective orientation of fault systems. As a result, the close correlation between fault orientations and hydrocarbon reservoirs is demonstrated. The method should be applied as an effective tool for hydrocarbon exploration in the East Sea.

1. Introduction

The essential significance of orientation analysis of fault systems for oil and gas exploration has been proved by many studies that have been carried out in the East Sea as well as all over the world. The study and determination of fault systems in the East Sea has been done over a period of many years with differences in grade and details determined. Especially, the fault systems in the Cenozoic basins have been meticulously studied by oil and gas exploration companies from inside and outside Vietnam. However, as yet, these studies apply only to faults within sedimentary basins, not to faults in the Pre-Cenozoic basement. In this paper, for analysis of fault orientations, all the fault data and information on oil and gas field distributions that are available in the study area have been collected. Most of these are the results of studies conducted by the Institute of Marine Geology and Geophysics and the Vietnam Petroleum Institute. Concurrently, the gravity data has also been interpreted to determine the faults that are present in the Pre-Cenozoic basement as well as in areas that have no fault data as yet.

In this paper, some sample areas have been selected to apply the method of orientation analysis of faults. In these sample areas the fault information are abundant and they are considered as the high oil and gas potential areas. The sample areas were selected from a large region, covering the whole continental shelf and they are representative of the different geological structures in the East Sea. The correlation between fault and oil and gas reservoirs is defined by analysing these fault orientations. The information on known oil and gas fields is compared with the study results in order to affirm the reliability of the method.

The results presented in this paper prove the significance and reliability of using orientation analysis of faults in oil and gas exploration, especially for offshore areas.

2. Orientation analysis of faults for oil and gas exploration

2.1. Database creation

2.1.1. Information on oil and gas fields in the study area

Collection and integration of information on known oil and gas fields are important for hydrocarbon exploration in other new areas. We can consider this as datum information that can be usefully applied for other geophysical methods. The spatial distributions of known oil and gas fields are consistent with geological structure and fault orientations. In this paper, the results from the orientation analysis of faults can be compared with the information on known oil and gas fields. As a result, one can produce comments and detailed plans for oil and gas exploration in different areas and at different levels. Most of the oil and gas field data were collected and integrated from project KC-09-02 (National Marine Research Project KC-09) [2, 6], which was carried out by the Institute of Marine Geology and Geophysics and the Vietnam Petroleum Institute during different periods (Fig.1).

2.1.2. Collection of fault information

Studies of faults in the East Sea have been carried out over the past many years. However, the studies with wide scope and of high quality only started in the 1980's. The results achieved have allowed the construction of maps of fault characteristics and distribution. More and more, fault characteristics are being upgraded and detailed by many marine research projects. Nevertheless, because of the diversity and dispersion of these data from surveys

and research projects, the maps of fault characteristics and distribution were constructed with differences in geographic projection and resolution as well accuracy. In project as KC-09-02 (2001 - 2005) [2], many maps, such as gravity, tectonics and deep structure, were constructed and these maps integrate all the newest information on fault characteristics in the East Sea.

In addition, many fault investigations have been undertaken by oil and gas companies and these investigations have accurately revealed characteristics the and distribution of fault systems. Most of the fault data are concentrated in the continental shelf, especially in the sedimentary basins such as Song Hong, Phu

Khanh, Cuu Long, Nam Con Son and Ma Lai - Tho Chu basins, where oil and gas exploration is most intense [6]. However, for deep basins and remote areas, the fault data are very sparse and inhomogeneous.

2.1.3. Determination of fault systems from gravity data

Though fault data in the East Sea are very abundant, most data are concentrated in the continental shelf and sedimentary basins. Therefore, in this study, the collection of the known fault data and the determination of unknown faults by interpreting gravity data were carried out simultaneously. Methods of analytical upward-downward continuation and horizontal gravity gradient and maximal gravity gradient were applied to determine 3D fault geometry. The processes of gravity data interpretation were divided into two steps: first step, calculation of horizontal gravity gradient at different high levels; second step, the maximal values of horizontal gravity gradient in the first step for locating the edges of geological bodies



Fig.1. Distribution of fault systems and oil-gas fields in the East Vietnam Sea (after the marine research projects at Institute of Marine Geology and Geophysics)

(such as faults) [1, 3, 5, 6, 7]. The map of gravity-fault distribution was constructed by integrating and linking locations of the maximal gravity gradient values.

Integrating and combining the results at items 2.1.1, 2.1.2 and 2.1.3, the map of distribution of fault systems and known oil and gas fields in the East Sea was compiled (Fig.1).

2.1.4. Fault information correction

The fault information was gathered from different sources; therefore errors such as their coordination, spatial distribution and existence are inevitable. The faults within the sedimentary basins are determined by seismic and gravity data, the faults in the Pre-Cenozoic basement



Fig.2. Distribution of sample areas using for orientation analysis of faults

and in areas with no fault data are only defined by using gravity data. For the purpose of this paper, the authors have compared and corrected the faults collected with those calculated in order to compile a unified map of fault distribution with a standard geographic projection (Fig.1).

2.1.5. Calculation of fault orientations

Orientation is one of the characteristics of linear features such as fault and shear zones. All the fault data were digitised and transformed to a unique geographic projection - Mercator WGS84. Calculation and representation of fault orientation are the major task in this paper. The software GeoMapVector, Ras2vec and MapInfo, Ilwis GIS packages were used in combination to do the task. In this study, the faults in the area are divided into 12 sample-areas, assigned from V1-V12. They are used to calculate the orientation of faults (Fig.2).

The GeoMapVector program for MapInfo was used to calculate the azimuth (trend, orientation) of faults in a MapInfo table. The azimuth direction chosen can be either from the first node in the fault-line towards the last node, or vice versa. For tables in an Earth projection the geodetic azimuth calculated is based on the WGS84 ellipsoid with azimuths given as the 360° angle clockwise from longitudinal North.

The calculating procedure works on the current selection of the faults and produces a new table with the orientation values of the faults. The orientation values of the faults are generated based on their length instead of usual frequency [4]. The program is useful for capturing the orientation of digitised line data such as faults and fractures and for analysis of these data.

2.1.6. Representation of fault orientation

Orientation is one of the most revealing characteristics of linear features, such as surface faults and basement faults. A rose diagram is the most effective way to represent the information on orientations of linear features [4]. The fault's orientations calculated in item 2.2.2 above were used for drawing the rose diagrams. Here, a fault's azimuth angle is chosen from 0 - 360° clockwise Northwards. Rose diagrams for all the faults acquired in the East Sea were generated by using Ilwis 3.0 GIS package (Figs.3 - 8).

Fig.3 shows the rose diagrams of orientations of faults systems in the North Bac Bo and Song Hong basins. It can be seen from the diagrams that the faults in these areas have two orientations: Southwest -Northeast and Southeast - Northwest. However, the main orientation of the faults is Southwest - Northeast, this reflects the major geological structure of the sedimentary basins. The faults with Southeast -Northwest direction are minor, which reflect the local geological structures that develop inside the sedimentary basins.

Fig.4 shows the rose diagrams of orientations of fault systems in the Southeast Hainan and Phu Khanh basins. The orientation of the faults in the Southeast Hainan basin is Southwest - Northeast and that in Phu Khanh basin is longitudinal. Besides, in the Phu Khanh basin there are two more, less frequent orientations of faults; these being Southwest - Northeast and Southeast - Northwest. This may be related with faults inside the sedimentary basin.



Fig.3. Rose diagrams representing orientations of faults in North Bac Bo and Song Hong basins (at sample V1 and V2)



Fig.4. Rose diagrams representing orientations of faults in Southeast Hainan and Phu Khanh basins (at sample V3 and V4)



Fig.5. Rose diagrams representing orientations of faults in Cuu Long and Nam Con Son basins (at sample V5 and V6)

The orientations of the faults in Cuu Long and Nam Con Son basins are represented in Fig.5. There are three orientations of faults in these areas, these are Southwest - Northeast, Southeast - Northwest and West - East, however, the major orientation is Southwest - Northeast. The Southwest - Northeast and longitudinal trend are two primarily orientations of the faults in the Nam Con Son basin.







Fig.7. Rose diagrams representing orientations of faults in Ma Lai - Tho Chu and Pattani basins (at sample V9 and V10)



subdued in the rose diagram (Fig.6). In the Southeast of the Ma Lai - Tho Chu basin (V8) area, the faults develop Northwest -Southeastwardly.

In the Northwest part of the Ma Lai - Tho Chu basin the orientations of faults are Southeast - Northwest and sub-longitudinal. In this area, the faults in sub-longitudinal direction are quite dense. In Pattani basin, the main orientation of the faults is longitudinal and the minor orientation is Northwest -Southeast (Fig.7).

In this paper, the fault's orientation in two adjacent areas of the East Sea, the Borneo and Chau Giang basins (V11 and V12 areas) are also analysed. In the depressed Borneo basin, the primary orientation of faults is Northwest - Southeast and consistent with the geological structure in the area. In the Chau Giang basin, the fault orientation is also Northwest - Southeast but it inclines towards a sublatitudinal direction (Fig.8).

3. Assessment of results

Based on the results from orientation analysis of faults and known oil and gas fields' information, it is reasonable to conclude that distribution of known oil and gas fields is quite consistent with orientation of the fault

Fig.8. Rose diagrams representing orientation of fault in Borneo and Chau Giang basins (at sample V11 and V12)

In the Tu Chinh - Vung May basin, the primary orientation of faults is Southwest - Northeast. The Southeast - Northwest direction is minor and quite systems in the East Sea. The correlation between fault orientation and oil and gas distribution in the study area can be generally described as follows: In the V1 and V12 areas, the distribution of the oil and gas fields is latitudinal. These are consistent with the orientation of the fault systems in the areas (Figs.1, 3 and 8).

In the V2 area, the Song Hong sedimentary basin, the fault orientation is Southeast - Northwest. The correlation between fault orientation and oil and gas fields' distribution can be seen clearly in Figs.1 and 3.

The V5 and V6 areas cover the Cuu Long and Nam Con Son sedimentary basins. Here, fault orientations are different but also consistent with the distribution of oil and gas fields (Figs.1 and 5).

Distribution of oil and gas fields in the V8, V9 and V10 areas are different in trends. These depend concretely on the geological structure in particular basins, but generally the distribution is quite consistent with fault orientation in the areas (Figs.1, 6 and 7).

Finally, in the V11- Borneo basin, the distribution of the oil and gas fields is Southeast - Northwestward. In this area, the faults are developed in only one orientation that is consistent with distribution of the known oil and gas fields (Figs.1 and 8).

4. Remarks and conclusion

Based on the results as summarised above, an assessment of the significance and reliability of fault orientation analysis for hydrocarbon exploration in the East Sea leads to some remarks and conclusions as follows:

The analysis in this study requires a tremendous amount of information concerning faults, the distribution of the known oil and gas fields and gravity data. Some of above-mentioned information is derived from interpretation of seismic and gravity data which must be digitised and created in standard format and represented in geographic projection.

The consistency in orientation between faults and the known oil and gas fields shows a close correlation between fault characteristics and the existence of oil and gas reservoirs. It is practical to conclude that any potential new oil and gas reservoirs, if they exist, will likely be associated with the fault's orientation.

From the achieved results, it can be concluded that the orientation analysis of faults should be applied as an effective tool for oil and gas exploration. It could be used for preliminary delineation of locations for more detailed geological and geophysical surveys in the East Sea.

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SYNTHESIS AND CHARACTERISATION OF TITANOSILICATES USED AS CATALYSTS FOR THE EPOXIDATION OF CYCLOHEXENE

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Summary

In this work the synthesis of TS-1 from a titanosilicate cogel precursor is reported. The synthesis parameters were altered to optimise both the cogel and resultant framework material. The titanosilicate materials were characterised using a range of techniques including EDX analysis, XRD, ²⁹Si NMR, IR, UV-vis and SEM. Those materials which demonstrated the most catalytic potential were used as catalysts for the epoxidation of cyclohexene reaction, in which the use of aqueous H_2O_2 and a urea- H_2O_2 adduct were compared. It was shown that the cogel precursors themselves exhibited some catalytic reactivity and selectivity for all of the catalysis reactions exploited. However the TS-1 materials were more catalytically active, which highlighted the need of the ordered framework for the most effective catalysis. The TS-1 materials prepared from the cogel precursors exhibited similar catalytic ability to those analogous standard materials prepared via conventional processes. Thus TS-1 preparation by the cogel route was shown to be a viable alternative preparation method to the conventional process.

1. Introduction

In 1983, Taramasso and co-workers reported the formation of a new material, via the isomorphous substitution of Si (IV) by Ti (IV), with the crystalline structure of silicalite-1 (MFI) [1]. The catalytic properties

of titanium silicalite-1 (TS-1) appeared to be unique and were attributed to the location of the titanium atoms on isolated lattice sites within a hydrophobic framework. It was reported that in oxidation reactions, with aqueous H₂O₂ as the oxidant, many organic compounds could be oxidised with high selectivity and reactivity. Additionally partial oxidation products could be obtained in high yields and almost all the oxygen available from H₂O₂ was used to produce the desired products [2]. Since industrialisation of the TS-1 catalyst, carried out successfully by EniChem in the mid-eighties, many efforts have been made towards the study of reactions involving this class of catalyst (Fig.1) [3 - 5]. TS-1 is currently used for two

processes on an industrial scale (phenol hydroxylation and cyclohexanone ammoximation) and several companies are developing a third process, propylene epoxidation.

Several different TS-1 materials were synthesised from the cogel precursors, variations included: titanium



Fig. 1. Common catalytic applications of TS-1

Cogel Code	Heteroatom Source	Si:Ti	Ті	Condensation Method	Condensation Reagent
1	Titanium butoxide	10	8.14g (23.00mmol)	Stirring	TPAOH
2	Titanium butoxide	80	1.02g (2.88mmol)	Stirring	TPAOH
3	Titanium butoxide	10	8.14g (23.00mmol)	Sonocation	TPAOH
4	Titanium butoxide	80	1.02g (2.88mmol)	Sonocation	TPAOH
5	Titanium butoxide	10	8.14g (23.00mmol)	Stirring	TEAOH
6	Titanium butoxide	80	1.02g (2.88mmol)	Stirring	TEAOH
7	Titanium butoxide	10	8.14g (23.00mmol)	Sonocation	TEAOH
8	Titanium butoxide	80	1.02g (2.88mmol)	Sonocation	TEAOH
9	Titanium isopropoxide	10	6.54g (23.00mmol)	Stirring	TEAOH
10	Titanium isopropoxide	80	0.82g (2.88mmol)	Stirring	TEAOH
11	Titanium isopropoxide	10	6.54g (23.00mmol)	Sonocation	TEAOH
12	Titanium isopropoxide	80	0.82g (2.88mmol)	Sonocation	TEAOH
13	Titanium ethoxide	10	5.25g (23.00mmol)	Stirring	TEAOH
14	Titanium ethoxide	80	0.66g (2.88mmol)	Stirring	TEAOH

Table 1. Specific synthesis details of titanium cogels synthesised

concentration and silylation. The physical and catalytic properties of TS-1 materials formed from the cogel precursors were compared to those of TS-1 materials formed from conventional means.

This work focused on the:

- Synthesis of TS-1 materials from cogel precursors and comparison of their physical and catalytic properties to those of TS-1 materials produced by a conventional process.

- Characterisation of the physical and catalytic properties of the cogel precursors and comparison with resultant TS-1 materials.

- Application of TS-1 in the epoxidation of cyclohexene.

2. Experimental

2.1. Cogel Synthesis

The table below (Table 1) gives specific details of the titanium cogels formed (TPAOH: tetra-*n*-propylammonium hydroxide, TEAOH: tetra-*n*-ethylammonium hydroxide).

2.2. TS-1 Synthesis

TS-1 materials were synthesised from the cogel precursors, these framework materials being prepared from both the calcined and as-prepared cogel precursors (Table 2). Standard TS-1 was synthesised by co-workers at Pune University, India according to procedures given in the patent literature and was treated as a standard for comparison [1].

Table 2. Details of TS-1 materials produced

Cogel Source	TS-1 Code	Calcined/As Prepared Cogel	
1	1 - 1	As Prepared	
1	1 - 2	Calcined	
2	2 - 1	As Prepared	
2	2 - 2	Calcined	
3	3 - 1	As Prepared	
5	3 - 2	Calcined	
	4 - 1	As Prepared	
4	4 - 2	Calcined	
F	5 - 1	As Prepared	
5	5 - 2	Calcined	
6	6 - 1	As Prepared	
0	6 - 2	Calcined	
7	7 - 1	As Prepared	
1	7 - 2	Calcined	
0	8 - 1	As Prepared	
0	8 - 2	Calcined	
0	9 - 1	As Prepared	
9	9 - 2	Calcined	
10	10 - 1	As Prepared	
10	10 - 2	Calcined	
11	11 - 1	As Prepared	
11	11 - 2	Calcined	
12	12 - 1	As Prepared	
12	12 - 2	Calcined	
13	13 - 1	As Prepared	
15	13 - 2	Calcined	
14	14 - 1	As Prepared	
14	14 - 2	Calcined	

2.3. Blank material synthesis

Blank framework materials were synthesised from cogel precursors containing no titanium.

2.4. Epoxidation of Cyclohexene

The formation of the epoxide product from cyclohexene in this research was undertaken by employing titanium inserted catalysts. The catalyst (100mg), solvent (anhydrous acetonitrile, 99.8%, 6.0g, 0.1mol) internal standard (mesitylene, 99.8%, 500mg, 4.2mmol) and cyclohexene (500mg, 99.5%, 6.1mmol) were stirred to allow the temperature to equilibrate (60°C, 30 minutes). The oxidising reagent (hydrogen peroxide, 30% (aq), 0.6g, 6.1mmol) was then injected into the mix. Aliquots (~0.5mL) were periodically removed from the mix and quenched, over 6 hours.

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3. Results and Discussion

3.1. Titanosilicate Materials

All of the cogel and TS-1 materials formed were fine white powders, however upon addition of aqueous H_2O_2 their colour changed to yellow.

EDX analysis was performed to evaluate the elemental composition of all TS-1 and cogel materials (Fig.2). All of the materials were pre-calcined to remove any organic residues. The percentage atomic composition of all of the materials was within 3.0% of the expected values (EDX accuracy ~ 1.0%).

XRD patterns of the cogels showed them to be amorphous with no long range order, regardless of the differences in synthesis procedure or titanium ratio (Fig.2). Conversely all of the TS-1 materials produced were crystalline and of framework type MFI. XRD patterns obtained were compared to those reported in the literature [10].

²⁹Si NMR data was used to evaluate the different types of silicon environment within the titanosilicate materials (Fig.3). The spectrum of the cogel material exhibited three peaks, relating to three different Q_n environments within the material, whilst the TS-1 material only revealed two. Thus the less ordered cogel material exhibited a wider range of silicon environments than the corresponding framework material.

The concentration of silanol groups in a material was calculated as a ratio of $Q_4/Q_{n'}$, where Q_4 was the number of silicon atoms present in silicalite Si(SiO)₄ environments and Q_n was silicon atoms in any silanol form ($Q_1 + Q_2 + Q_3$). The value of this ratio for the cogel examined was 0.28 and for the TS-1 was 0.75. Therefore the cogel had a much higher concentration of terminal hydroxyl groups than the TS-1 and was hence comparatively a more hydrophilic material [11]. The terminal silanol groups are sometimes referred to as Brønsted acid sites, thus the Brønsted acidity



Fig.2. Titanium composition (%) of TS-1 (blue) and cogel (red) materials of both Si:Ti 10 (solid colour) and Si:Ti 80 (striped)



Fig.3. XRD patterns of calcined cogel (1-4) and TS-1(5-9) materials. (1: Cogel 6, 2: Cogel 1, 3: Cogel 10, 4: Cogel 14)(5: TS-1 standard, 6: TS-1 6-2, 7: TS-1 1-2, 8: TS-1 10-1, 9: TS-1 14-2)

of any silicate material can be discussed regardless of the nature of the inserted heteroatom.

IR data was collected for pre-calcined, dehydrated cogel and TS-1 materials (Fig.5). Further evidence of titanium insertion in the zeolite framework was the presence of a band at 960cm⁻¹ relating to the stretching vibration of [SiO₄] units bound to tetrahedrally coordinated titanium atoms. The appearance of this band in the cogel spectrum confirmed that the cogel contained titanium centres of the desired tetrahedral coordination geometry prior to crystallisation. It was notable that upon addition



Fig.5. IR spectra of titanosilicate materials (Dashed line: 550cm⁻¹ and 960cm⁻¹)

of aqueous H_2O_2 to the observed materials the intensity of the band at 960cm⁻¹ decreased, this was attributed to coordination of H_2O_2 at the titanium sites. However the 960cm⁻¹ band could be recovered by calcination of the samples, which removed the coordinated H_2O_2 , thus providing more evidence that the incorporated titanium heteroatoms were capable of forming the peroxy species necessary for effective catalysis. The signal at 550cm⁻¹ was characteristic for orthorhombic MFI frameworks and was visible in all TS-1 materials.

Fig.6 depicts the UV-vis spectra of standard TS-1, TS-1 8-2 and the corresponding precursor cogel 8. In all cases there was no appreciable adsorption band (~ 330nm) thus portraying an absence of bulk TiO_2 phases, although the presence of small TiO_2 clusters cannot be completely discarded. The narrow bands of the TS-1 materials, centred ~ 220 nm, confirmed that the titanium atoms occupied mostly tetrahedral positions within the zeolite framework.

The cogel spectrum however depicted a broader band shifted to a higher wavelength, which suggested that titanium atoms were present in configurations other than tetrahedral. As predicted, UV-vis spectra of the cogel materials with different titanium concentrations exhibited broad bands in the range 200 to 300nm, which demonstrated that different titanium environments coexisted in these materials (Fig.7). This band was broader in the spectrum of cogel 7, which had a higher titanium concentration than cogel 8, additionally there was another peak at ~ 310nm which was attributed to either extra framework titanosilicate species or bulk TiO₂ phases.



Fig.6. UV-vis spectra of cogel 8 (black), TS-1 8-2 (green) and standard TS-1 (red) (Navy line = 220nm)

The spectra obtained from TS-1 materials prepared from these cogels exhibited similar properties to each other. TS-1 7-2 (higher titanium concentration) produced a broader peak at ~ 220nm, and an additional peak at ~ 310nm. The UV-vis results obtained thus echoed the IR results wherein the materials with Si:Ti 80 appeared to contain titanium centres with predominately tetrahedral geometry, whilst the materials with Si:Ti 10 had titanium centres with a range of coordination geometries.

SEM images of the cogel materials showed no ordered morphology regardless of the synthesis parameters employed (Fig.8). SEM images of the TS-1 materials showed them to be of roughly spherical morphology with an average diameter of 0.5µm, compared with cubic crystals of the standard TS-1 with 0.15µm diameter [13]. The size and morphology of the TS-1 materials prepared from cogel precursors appeared comparable regardless of the synthesis parameters altered to produce them (titanium concentration, titanium source, condensation reagent, condensation method, use of calcined cogel precursor). It was reported that particle size influenced the catalytic activity of all molecular sieves, but it was especially influential in the case of TS-1. Reportedly the average particle size of an active TS-1 catalyst should be < 0.5µm, thus these TS-1 materials appeared to be at the limit of the ideal [5, 14].

BET surface area measurements were undertaken by co-workers at Pune University, India. The results found the cogel (10) material to have a surface area of 694m²g⁻¹ and the corresponding TS-1 (10-2) to have a surface area of 416m²g⁻¹. The surface area of TS-1 was close to the values reported in the literature of ~ 400m²g⁻¹ for TS-1 materials prepared by standard means.⁷ The surface area of the cogel was higher than that of the TS-1 materials and was close to the value of ~ 700m²g⁻¹ reported for xerogels in the literature [16]. The high surface area of these titanosilicates was encouragingly similar to catalytically

active materials, wherein the higher the surface area the more easily assessable the active sites are for the reagent materials.

3.2. Silicalite Materials

Silicalite materials (containing titanium no heteroatoms) were synthesised for use as standard materials, they were characterised employing some of the techniques utilised for the titanosilicate materials. Addition of aqueous H₂O₂ to any of the samples did not result in an observable colour change. XRD results confirmed the cogel to be amorphous and the silicalite-1 material to have the desired MFI framework. IR results for both the cogel and framework materials showed no noticeable peak at 960cm⁻¹ and no peak at 550cm⁻¹ for the silicalite-1 materials (Fig.5). UV-vis results showed no peaks for any of the standard materials tested.



Fig.7. UV-vis spectra of cogel and TS-1 materials with varying titanium concentrations: Cogel 7 (Si:Ti 10, solid red line), Cogel 8 (Si:Ti 80, solid black line),TS-1 7-2 (Si:Ti 10, dashed red line), TS-1 8-2 (Si:Ti 80, dashed black line)



Fig.8. SEM images of i) Cogel 8, ii) and iii) TS-1 8-2

3.3. Epoxidation of Cyclohexene

The catalytic activity of titanosilicate materials for many different reactions has been well recognised and reported [17]. The surface structure of TS-1 has been described in terms of i) the state and framework coordination of titanium ii) surface hydroxyl groups present in the form of silanols and titanols. These structural characteristics influence the materials' catalytic reactivity and selectivity. However an amorphous $TiO_2 - SiO_2$ catalyst consisting of 2% TiO_2 dispersed on high-surface area silica has been reported to be an active and selective catalyst for the epoxidation of alkenes, thus demonstrating that a three-dimensional framework is not essential for active catalysis [18, 19].





Fig.10. Cyclohexene conversion (%) for TS-1 (blue) and cogel (red) materials after 6 hours of reaction

The catalytic reactivity of both the TS-1 and cogel materials were tested for the epoxidation of cyclohexene. Only those titanosilicate materials with Si:Ti 80, which exhibited titanium centres in the desired optimal environment for catalysis, were used as catalysts. After 6 hours of reaction the cogel and TS-1 materials showed similar catalytic reactivity, with a cyclohexene conversion of ~ 20% (Fig.9).

All of the titanosilicate materials showed some reactivity for the epoxidation of cyclohexene (Fig.9). The percentage conversion of cyclohexene by the standard TS-1 (17.7%) and the cogel prepared TS-1 materials (16.8%) were comparable.

Cogel materials condensed under sonocation were overall slightly more catalytically reactive compared to materials condensed whilst stirred. The predictably lower reactivity of the stirred materials was due to the nature of the catalytically active titanium centres which (as discussed) were less tetrahedral than those atoms in materials condensed under sonocation. Cogel materials condensed using either TPAOH or TEAOH demonstrated similar catalytic reactivities to the TS-1 materials synthesised from them. Both UV-vis and IR data demonstrated the similarities of the titanium centres within these materials, thus it was predicted they should exhibit comparable catalytic reactivity.

TS-1 materials synthesised from as-prepared cogel precursors consistently had lower catalytic reactivity compared to similar materials prepared from calcined

> precursors. The titanium centres were on average more tetrahedral in TS-1 materials prepared from calcined cogel precursors. Both the cogels and corresponding TS-1 materials which contained titanium from a titanium ethoxide source (cogels 13 and 14, TS-1 13-1, 13-2, 14-1, 14-2) had lower catalytic reactivity (cyclohexene conversion) than those materials formed using other titanium sources. This was again expected from the IR and UV-vis results which showed the titanium centres in these materials on average to be less tetrahedral.



Fig.11. Catalytic selectivity of i) cogel 8, ii) TS-1 8-2, iii) standard TS-1, for the epoxidation of cyclohexene (Other denotes combined ketone and mono-alcohol selectivity)

The catalytic selectivity of cogel and TS-1 materials towards epoxide formation decreased as the reaction continued, the epoxide degraded to form the diol product (Fig.11). The cogel selectivity for epoxide formation was initially very low (~ 10%) and after 6 hours had decreased further still (< 5%). Conversely TS-1 materials exhibited a high initial selectivity towards epoxide formation (~ 75%), which again decreased (~ 60%) to produce the diol over 6 hours of reaction.

Thus the selectivity towards the formation of the epoxide was higher for TS-1 compared to cogel materials. The continued reaction to produce the diol product has been reported to occur via acid catalysed hydrolysis of the epoxide [20]. Thus it was hypothesised that the observed selectivities were due to the highly disordered structure of the cogel materials which contained a higher concentration of hydroxyl groups, in contrast to the crystalline TS-1 materials.

The TS-1 synthesised from the cogel precursor exhibited analogous catalytic selectivity to the TS-1 prepared by conventional means (~ 60%). No notable differences in the epoxide selectivity of all TS-1 or all cogel materials were observed, regardless of the alteration of the synthesis parameters (Fig.11).

All catalysts were collected and re-calcined after each experiment, for some catalysts their ability to regenerate was then tested (standard TS-1, TS-1 8-2, cogel 8). Results of all the catalysts retested were within 3% of those reported herein. Control catalytic experiments were also performed with either no catalyst present or using blank silicalite materials as the catalyst, these yielded no products.

3.4. Urea-H,O, Adduct Alteration

When water is present in the epoxidation of cyclohexene reaction, the acid catalysed conversion of epoxide to diol can occur. Hence to enhance epoxide selectivity a non-aqueous source of H_2O_2 was used, a urea- H_2O_2 adduct, which slowly released H_2O_2 into solution [21]. Additionally the urea adduct can bind to terminal hydroxyl groups on the catalyst, thus preventing these sites being employed as acid centres for epoxide degradation. Whilst the catalytic reactivities of the TS-1 materials under the altered conditions were comparable with each other they were vastly different from the reactivity of the cogels (Fig.13). After 6 hours of reaction the TS-1 materials showed ~ 30% cyclohexene conversion whilst the cogel showed < 5% cyclohexene conversion.

This dramatic decrease in cogel selectivity was hypothesised to be due to the binding of the urea adduct



Fig.12. Epoxide selectivity for TS-1 (blue) and cogel (red) materials after 6 hours for the epoxidation of cyclohexene reaction







Fig.14. Cyclohexene conversion (%) for TS-1 (blue) and cogel (red) materials after 6 hours, using urea-H₂O₂ oxidant

to the surface hydroxyl groups. These hydroxyl groups could theoretically have been titanols or silanols, with either resulting in the lowering of the catalysts' reactivity. In the case of the titanol groups it has been reported that urea interacts very strongly with titanium centres, in some systems preventing any catalytic reaction occurring [5]. Whilst the binding of the adduct to the highly concentrated silanols on the cogel surface could have hindered access to the titanium active sites of the bulky cyclohexene reagent.



Fig.15. Catalytic selectivity of i) cogel 8, ii) TS-1 8-2, iii) TS-1 standard, for the epoxidation of cyclohexene using urea-H₂O₂ oxidant. (Other denotes combined ketone and mono-alcohol formation (%))


Fig.16. Epoxide selectivity for TS-1 (blue) and cogel (red) materials for the epoxidation of cyclohexene using urea-H,O, oxidant

Alteration of the oxidant from aqueous H_2O_2 to the urea- H_2O_2 adduct greatly altered the reactivity of all of the titanosilicate materials (Fig.14). The reactivity of the TS-1 materials increased from ~ 20% cyclohexene conversion to ~ 30%. It was theorised that the comparative increase in hydrophilicity of the reaction medium enabled release of the organic products formed from the more hydrophobic TS-1 material. Conversely the reactivity of the cogel materials decreased (from ~ 20% cyclohexene conversion to ~ 5% conversion), and this could have been due to binding of the urea to either the titanol or silanol groups.

The catalytic selectivity of cogel and TS-1 materials towards epoxide formation remained approximately constant as the reaction continued, with no obvious epoxide degradation to the diol (Fig.15). Compared to results utilising aqueous H_2O_2 , the epoxide selectivity of the TS-1 materials increased from ~ 60% to ~ 90%. The cogel materials also exhibited increased (to a larger extent) epoxide selectivity, rising from ~ 5% to ~ 60%.

The epoxide selectivity of the TS-1 materials remained higher than that for the cogel materials and appeared stable over the reaction time (Fig.16). It was therefore concluded that by altering the oxidant to the urea- H_2O_2 adduct, the acid sites of the titanosilicate materials were prevented from catalysing the degradation of the epoxide [22]. It was shown that the cogel materials contain a higher concentration of terminal hydroxyl groups which catalyse diol formation. Potentially not all of these groups were neutralised by the urea adduct, thus explaining the lower epoxide selectivity of these materials.

4. Conclusions

In summary, the cogel and TS-1 materials reported herein had good catalytic potential, containing titanium heteroatoms in the desired coordination tetrahedral geometry. Additionally all materials appeared capable of forming the necessary titanium peroxy species required for oxidation catalysis. However the catalytic ability may have been limited by the large size of the

TS-1 crystals. Materials prepared with either the titanium isopropoxide or the butoxide showed comparable characteristics whilst materials prepared with titanium ethoxide were shown to have titanium heteroatoms in a wider range of coordination environments.

The epoxidation of cyclohexene reaction using these titanosilicate materials demonstrated that alteration of these synthesis parameters only had a minor effect upon the catalytic properties of the materials produced. For epoxidation of cyclohexene, the cogel and TS-1 materials exhibited similar catalytic reactivity but vastly different selectivity. The epoxide selectivity of the TS-1 materials was comparable to values reported in the literature (~ 60%), whilst the epoxide selectivity of the cogel was extremely poor (< 5%). The epoxide selectivity of all of the titanosilicate materials decreased over time due to the acid catalysed formation of the diol. The catalytic ability of the TS-1 materials prepared from the cogel precursors is comparable to those TS-1 materials prepared from conventional means.

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SYNTHESIS AND STRUCTURE SOLUTION OF TRIETHYLENEDIAMINE DIRECTED MICROPOROUS MATERIALS

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Summary

By a combination of single crystal and high-resolution powder diffraction studies, the authors aimed to gain further insights into how the organic template molecules may direct the production of a specific microporous framework. Attention was focused on the use of cyclic mono and diamines as structure directing agents to produce small pore microporous materials. The zeolite analogue Chabazite, along with two novel framework types, were synthesised by the use of the triethylenediamine (DABCO) organic template. From an initial mixed phase sample, all three crystal morphologies have been successfully prepared in their phase pure form by optimising the synthesis conditions for each individual material. With the DAF-6 (Davy Faraday-6) pure AIPO phase isolated, the addition of different cations into the synthesis gel produced the CoAIPO Chabazitic phase and the calcium-substituted DAF-7 framework, to the authors' knowledge the first open framework structure containing calcium in a framework position.

1. Introduction

Several linear, branched and cyclic amines have been successfully used as templating agents in the synthesis of chabazite-type small pore aluminophosphates, for example triethylamine [1, 2] piperidine [3, 4] and cyclohexylamine [5, 6]. A number of triethylenediamine (DABCO) derivatives, for example 1.1'-alkylenedi(4-aza-1-azonia-2.5-dimethylbicyclo[2, 2, 2]octane are known to direct the formation of high-silica zeolite systems [7, 8]. In the amine form DABCO has also been used in the synthesis of three-dimensional open-framework Co²⁺ and Zn²⁺ phosphates [9] and more recently, a microporous cobalt-gallium phosphate [10] designated CGF by the Structure Commission of the International Zeolite Association.

The aim of the current work was to synthesise an aluminophosphate-based material with a small pore structure, using triethylenediamine (DABCO) in the amine form as a structure-directing agent. Our expectation was that the selected template would form a small pore type material quickly and in phase pure form, with little or no extraneous microporous phases. The Co²⁺-substituted form would be synthesised, to endow the framework with some catalytic properties. The organic template used in this work is shown Fig.1.

One of the inherent problems with the detailed structural characterisation of these materials is the

difficulty in obtaining a single crystal large enough for study using conventional laboratory single-crystal diffraction. A consequence of this is that many of the related structures have been solved by combining powder diffraction data and some single-crystal data and in some cases computer simulations as well [10 - 16]. With the introduction of the micro-crystal diffraction facility Station 9.8 at the Daresbury Synchrotron Radiation source [17] it is now routinely possible to collect diffraction data from crystals as small as 15 x 15 x 15µm.

2. Experimental

2.1. Synthesis

Cobalt-substituted aluminophosphate (CoAIPO) was prepared using triethylenediamine as the template. Cobalt and other heteroatoms were also substituted in the framework at the synthesis stage.



Fig.1. Structure of the template species triethylenediamine (DABCO). The nitrogen site is shown in blue, the carbon in green and the hydrogens are white

An aqueous gel was prepared using aluminium hydroxide, cobalt acetate tetrahydrate, 85% phosphoric acid, the template and distilled water. A small amount of water was added to the cobalt acetate until it dissolved. The remainder of the water was added to the phosphoric acid. The aluminium hydroxide was added to the acid/ water mix, followed by the cobalt acetate solution; the template was added last.The initial gel composition for the synthesis was:

0.9 AI_2O_3 : 1.0 P_2O_5 : 0.1 $Co(OAc)_2.4H_2O$: 1 DABCO : 40 H_2O

The gel was stirred vigorously after each addition to ensure thorough mixing. The resultant gel was then placed in a PTFE liner and heated hydrothermally in a stainless steel autoclave at 190°C for 24 hours.



Fig.2. Powder X-ray diffraction patterns for a standard chabazite sample (blue) and the prepared sample (purple). It is clear that the prepared structure contains chabazite and an impurity phase. Intensities are arbitrary and the spectra have been offset vertically for clarity





2.2. Characterisation

Phase purity was checked by powder diffraction, recorded with a Siemens D500 diffractometer. Singlecrystal data for this work were collected at the microcrystalline diffraction facility on station 9.8 of the Daresbury SRS [17] with typical data collection times of around 4 to 6 hours. The crystal was mounted on a glass fibre, attached to a standard goniometer head. Data were collected at 150K, to minimise the thermal motion of the template. All structure solutions and refinements were carried out using the SHELXTL/SHELX-97 suite of programs [20]. All the data collections and post-collection integration data processing were performed by the SMART and SAINT software provided with the detector to give a final hkl file ready for solving. All of the direct

> method solutions were completed with the SHELX/SHELXTL suite of programs. SEM was taken by JEOL JSM-6480LV in University College London.

> In this work, the X-ray Rietveld system (XRS-82) was used in the refinement of the X-ray powder data. In all refinements, the background was subtracted.

3. Results and discussions

3.1 Structure of pure AIPO, DAF-6 and DAF-7 by XRD, Single-crystal and SEM

The diffraction pattern is shown in Fig.2, along with the pattern for a standard chabazite sample generated from the Atlas of Zeolite Structure Types [18]. It is clear that the prepared structure contains chabazite and an impurity phase. Attempts to index all the reflections did not produce a unique solution, corroborating the optical microscope observations.

Examination by optical microscopy revealed three distinct crystal morphologies; two colorless, (hexagonal and rhombohedral crystal types) and one rectangular. The rectangular crystals are clearly blue, indicating their cobalt content. These distinct phases were separated for analysis by EDAX. This revealed the presence of calcium in the rhombohedral type crystals, approximately 12%. No traces of calcium were found in either of the other two morphologies, therefore establishing three distinct structures, A CoAIPO, pure AIPO and a calcium-containing phase.

Subsequently a pure phase was obtained for each of the three crystal morphologies and the CoAIPO phase



Fig.4. Optical picture of a crystal form the Chabazite-type material

1	Chemical formula	$AI_{0.77}Co_{0.23}PO_{4}.N_{0.12}C_{0.34}$
2	Formula weight	112.84
3	Temperature	150(2) K
4	Wavelength	0.69310Å
5	Crystal system, space group	Hexagonal, R3
		$a = 13.747(8)$ Å $\alpha = 90^{\circ}$
6	Unit cell parameters	$b = 13.747(8)$ Å $\beta = 90^{\circ}$
		$c = 15.339(16)$ Å $\gamma = 120^{\circ}$
7	Cell volume	2510(3)Å ³
8	Z	21
9	Calculated density	1.567g/cm ³
10	q range for data collection	2.1 to 29.3°
11	Index ranges	h - 19 to 16, k - 8 to 19, l - 20 to 2
12	Completeness to q = 29.3°	93.0%
13	Reflections collected	5,846
14	Independent reflections	2,880 (R _{int} = 0.0982)
15	Reflections with $F^2 > 2s$	2,275
16	Structure solution	direct methods
17	Refinement method	Full-matrix least-squares on F ²
18	Final R indices [F ² > 2s]	R1 = 0.0634, wR2 = 0.1659
19	R indices (a ll data)	R1 = 0.0754, wR2 = 0.1758
20	Goodness-of-fit on F ²	1.098
21	Largest and mean shift/su	0.138 and 0.023
22	Largest diff. peak and hole	0.76 and - 0.90e Å ⁻³

was isolated at 170° C. The diffraction pattern is shown in Fig.3, along with the pattern for a standard chabazite sample. It is clear that the two spectra match very well, with no extra reflections in the sample, indicating that the only phase present is the Chabazite type material. The peak positions also match those expected from the Atlas of Zeolite Structures [19]. When studied with an optical microscope the sample is compiled of blue rectangular crystals. Optical pictures of the sample are shown in Fig.4. The crystal size of the sample ranged from $10 \times 10 \times 20$ mm to $30 \times 30 \times 40$ mm.

A single crystal with dimensions 30 x 30 x 40mm was chosen and data were collected and analysed using the SHELXTL/SHELX-97 suite of programs [20], results shown in table below.

It was possible to obtain a precise structure for the chabazite material. The space group was found to be R3, with unit cell dimensions a = 13.747(8), c = 15.339(16). Initially we had found the symmetry of the as-prepared material to be R $\overline{3}$. Attempts were made to refine the structure in this space group; however, no satisfactory solutions were found for the disorder in the template.

It is noted that removing the inversion centre also points to some cobalt ordering within the double sixring. With the structure being refined in the space group R3 there are 4 T atom positions. The cobalt content was refined and the final value came to 23% cobalt substitution. Fractional coordinates and U_{iso} for the structure are given in Table 2 and a view of the structure is shown in Fig.5.

It was found that the template molecules were situated to one side of the framework cage and were well ordered, thus easily enabling the location and refinement of the DABCO molecule to accurately determine the position and orientation of the molecules (Fig.5). Hydrogen atoms of the template were given idealised positions using the HFIX/AFIX commands within SHELXL [20] and refined using isotropic displacement parameters. The final structure solution, refined in R3, clearly shows

Atom	x	У	z	Uiso
AI(1)	0.99631(11)	0.22871(12)	0.65865(11)	0.0207(4)
Co1	0.99631(11)	0.22871(12)	0.65865(11)	0.0207(4)
A l (2)	1.23079(8)	0.23126(8)	0.45911(6)	0.0194(3)
Co(2)	1.23079(8)	0.23126(8)	0.45911(6)	0.0194(3)
P(1)	1.22973(8)	0.23111(9)	0.66360(6)	0.0137(2)
P(2)	1.23170(12)	0.00107(12)	0.46024(12)	0.0454(5)
O(1)	0.9027(4)	0.1011(5)	0.6852(3)	0.0674(17)
O(2)	1.1229(3)	0.2453(3)	0.6906(3)	0.0482(12)
O(3)	1.2709(3)	0.2695(3)	0.5608(3)	0.0269(9)
O(4)	1.3229(3)	0.3418(4)	0.3938(3)	0.0423(12)
O(5)	1.0951(4)	0.1968(4)	0.4453(4)	0.0718(18)
O(6)	1.2434(4)	0.1208(4)	0.4352(4)	0.0632(14)
O(7)	1.2672(7)	0.0127(7)	0.5460(7)	0.092(3)
O(8)	1.3144(5)	0.0217(5)	0.3934(4)	0.0823(17)
N(1)	1.0000	0.0000	0.1145(13)	0.131(6)
N(2)	1.0000	0.0000	0.272(2)	0.150(5)
C(1)	1.1090(17)	0.055(2)	0.1456(12)	0.092(7)
C(2)	1 1 38(3)	0.0940(15)	0.2279(13)	0 165(14)

Table 2. Atomic coordinates and equivalent isotropic displacement parameters (\hat{A}^2)for the as-prepared Chabazite



Fig.5. Schematic views of the CoAIPO structure refined from data collected at 150K. 2 views are shown for clarity, and to clearly show the template location and orientation. Note only one template species per cage



Fig.6. Schematic showing the preferred cobalt sites, as blue spheres; the substituted aluminium site preference is in the lower ring of the double six-ring building unit

the presence of only one ordered template within the cage, positioned off-centre towards one end.

Analysis of the Chabazite-related DAF-5 material by Sankar et al [21] also showed only one template

contained within the cage, although the 4-piperidinopiperidine template used here occupies much more space within the cage, making a second spatially impossible.

The position of the DABCO template within the cage suggests an ordering of the substituted cobalt within the framework, with the cobalt preferentially substituting specific sites in the double six-rings. This is demonstrated by an imbalance in the substituted cobalt values on each of the aluminium sites, where a 1:4 cobalt substitution preference for one aluminium site is shown. The location of the preferred cobalt ion locations within the framework is shown in Fig.6.

Attention now focuses on the unidentified CaAlPO remaining two morphologies, and developing a phase pure synthetic route to one or both of these novel materials. As EDAX analysis identified one as a pure aluminophosphate and one containing calcium, two separate syntheses would be required. In order to obtain the pure aluminophosphate material as the major phase, a much shorter synthesis time and higher temperatures were required. The gel composition is shown below; it was heated at 190°C. The pH of the starting gel was 7.0.

1.0 Al₂O₃: 1.3 H₃PO₄: 1.2 DABCO: 40 H₂O

The CaAIPO phase was prepared using calcium carbonate as the calcium source. The gels were prepared in a similar manner to the CoAIPO synthesised earlier, using the compositions shown below. The pH of the starting gel was 7.0.

0.80 Al₂O₃ : 1.3 H₃PO₄ : 0.20 CaCO₃ : 1.2 DABCO : 40 H₂O

The gel was heated in a PTFE liner under hydrothermal conditions in a stainless steel autoclave at 170°C for 3 days.

White crystalline material was produced and suitable single crystals were obtained for microcrystal analysis.

X-ray diffraction patterns of the materials formed are shown in Fig.7 and Fig.8 respectively. A pure phase was



Fig.7. Powder X-ray diffraction patterns for DAF-6 in the as-prepared form and simulated pattern from single-crystal analysis. Intensities are arbitrary and the spectra have been offset vertically for clarity



Fig.8. Powder X-ray diffraction patterns for DAF-7 in the as-prepared form and simulated pattern from single-crystal analysis. Intensities are arbitrary and the spectra have been offset vertically for clarity



(a) (b) **Fig.9.** Optical picture of the crystal morphology for the pure AIPO DAF-6 material (a) and DAF-7 CaAIPO material (b)

produced for both gel compositions; the powder X-ray diffraction patterns were compared to the simulated XRD pattern from the single-crystal refinement. The crystals with hexagonal morphology were denoted as DAF-6, (Davy Faraday-6) and the rhombehedral shaped ones were referred to as DAF-7.

Optical pictures of the sample are shown in Fig.9. The crystal size of the samples ranged from $40 \times 40 \times 5$ mm to $40 \times 30 \times 10$ mm.

3.2. Structure solution of DAF-6

In order to determine the absolute structure and location of the template molecule inside the DAF-6 framework, single-crystal diffraction techniques were employed, using microcrystal diffraction techniques at Station 9.8, Daresbury SRS [17]. Crystallographic details for the refinement are given in Table 3; definitions of R1 and wR2.

The structure was refined in the space group R3c, with unit cell dimensions of a = 14.0612(7)Å and c = 42.403(2)Å. Within the structure two template molecule sites were found, both very disordered. Unfortunately the void space produced in this structure has only very small pore openings with only minimum access into the framework (Fig.10). However, two octahedrally coordinated aluminium sites were formed within the structure blocking what could have been a larger pore opening and creating a small cage inside the structure, as shown in Fig.10.

The Al³⁺ octahedral site shows four of the oxygen atoms connected to the phosphorus site, i.e. framework oxygens and two of the oxygens belonging to water molecules present in the voids created by the structure. The high quality single-

crystal data enabled accurate location of the disordered template molecules. The octahedral aluminium along with the template molecules are shown in Fig.11.

1	Chemical formula	AI ₁₁ P ₁₂ N ₈ O ₄₈ . C ₁₂ H ₂₇
2	Formula weight	1719.84
3	Temperature	150(2) K
4	Wavelength	0.6923Å
5	Crystal system, space group	Trigonal, R3c
		$a = 14.0612(7)$ Å $\alpha = 90^{\circ}$
6	Unit cell parameters	$b = 14.0612(7)$ Å $\beta = 90^{\circ}$
		$c = 42.403(2)$ Å $\gamma = 120^{\circ}$
7	Cell volume	7,260.6(6)Å ³
8	Calculated density	2.360g/cm ³
9	q range for data collection	2.48 to 25.00°
10	Completeness to q = 25.0°	94.0%
11	Reflections collected	5,846
12	Independent reflections	2,880 (R _{int} = 0.0982)
13	Reflections with F ² > 2s	2,275
14	Structure solution	direct methods
15	Refinement method	Full-matrix least-squares on F ²
16	Final R indices [F ² > 2s]	R1 = 0.0377, wR2 = 0.0968
17	R indices (all data)	R1 = 0.0414, wR2 = 0.0986
18	Goodness-of-fit on F ²	1.127
19	Largest and mean shift/su	0.046 and 0.010
20	Largest diff. peak and hole	0.504 and -0.667 e Å ⁻³

Table 3. Crystallographic details for as-synthesised pure AIPO DAF-6



Fig.10. Schematic showing the limited access into the framework for DAF-6. With the octahedral aluminium blocking the pore access and creating the cage structure, shown with and without the template



Fig.11. Schematic showing the template location within the structure. The octahedral aluminium sites are shown here are yellow spheres. The hydrogen atoms have been omitted for clarity



Fig.12. Schematic of the first template site. The template is clearly shown disordered over two locations

The disorder at the template locations is clearly visible in Fig.12, where only a general idea of how the template molecule is orientated can be shown. A more detailed study of the two template locations revealed a more accurate picture of the template orientation. In both cases it was found that the organic molecule was occupying two offset positions at each of the sites.

The second template site shows two possible orientations, not translated as in the first location, but rotated about the nitrogen positions as shown in Fig.13. Analysis of the bond lengths and angles clearly shows the presence of two aluminium octahedral sites within the structure (Table 4).

3.3. Structure solution of DAF-7

A crystal of size 40x30x10mm was studied and the structure was refined in the triclinic space group $P\overline{1}$. The cell dimensions were a = 9.5527(10)Å, b = 9.9126(10)Å, c = 12.2629(13)Å, and $\alpha = 69.832(3)^\circ$, $\beta = 73.186(3)^\circ$, $\gamma = 82.214(3)^\circ$. The disorder on the template molecule is such that only its general location within the framework can be determined and as such the hydrogens have been omitted for clarity. Crystallographic details for the refinement are given in Table 5; the structure solution and refinement were carried out using the SHELXTL/SHELX-97 suite of programs [20].

The DAF-7 structure appears to be more open and complex than the DAF-6 structure. There are 8-membered ring channels in two different directions, as shown in Fig.5. Furthermore one of the aluminum sites is fully occupied instead by Ca²⁺ ions. EDAX analysis of the crystal clearly shows that the rhombohedral



Fig.13. Schematic of the second template site. The template is clearly shown disordered, with the rotation to the second template occupation about the nitrogen positions

Table 4. Selected bond lengths and angles for DAF6, highlighting
the coordination geometry of the two octahedral aluminum sites

Atom Pair	Bond Length (Å)	Average Bond Angle	Degrees
A I 1 - O8	1.934(5)	O-Al-O	90.05
A I 1 - O8B	1.934(5)		
A l 1 - O13A	1.846(4)		
A I 1 - O8A	1.934(5)		
A l 1 - O13	1.846(4)		
A I 1 - O13B	1.846(4)		
A l 2 - O10	1.920(5)	O-A I -O	90.23
Al2 - 010D	1.920(5)		
Al2 - 012C	1.878(5)		
Al2 - 010C	1.920(5)		
A l 2 - O12	1.878(5)		
A l 2 - O12D	1.878(5)		

crystals have ~12% calcium present. We did not find any extra-framework Ca^{2+} ions in the structure solution.

Upon closer inspection of the structure and bond distances and angles (listed in Table 6), it is clear that one of the Al³⁺ sites is five-coordinate, with a water or a terminal hydroxyl group bonding to the underside to form the fifth and longest oxygen bond. The Ca²⁺ sites have octahedral coordination, with four of the oxygen atoms linked to phosphorus and two of the oxygen atoms belonging to either water molecules or terminal hydroxyl groups.

To the best of the author's knowledge this is the first report detailing an open framework structure containing Ca²⁺ in a framework position. Although calcium salts are added in the starting gel mixture in the synthesis of zeolites, in all other cases the calcium ions are located only in the extra-framework positions. The reason why Ca²⁺ ions can be incorporated in an open framework AIPO structure rather than silica may be related to the ease with which we have been able to replace an Al³⁺ ion by divalent cations in an AIPO rather than replace Si⁴⁺ ions in microporous silicates.

In addition, it appears that the template molecule

Table 5. Crystallographic data and structure refinement details for the as synthesised CaAIPO material DAF-7

1	Chemical formula	$CaAI_{3}P_{4}O_{18}$. N ₂ C ₆ H ₅
2	Formula weight	638.02
3	Temperature	150(2)K
4	Wavelength	0.6931Å
5	Crystal system, space group	Triclinic, P1
		$a = 9.5527(10)$ Å $\alpha = 69.832(3)^{\circ}$
6	Unit cell parameters	$b = 9.9126(10)$ Å $\beta = 73.186(3)^{\circ}$
		$c = 12.2629(13)$ Å $\gamma = 82.214(3)^{\circ}$
7	Cell volume	1042.58(19) Å ³
8	Z	2
9	Calculated density	2.032g/cm ³
10	q range for data collection	2.2 to 24.0°
11	Completeness to q = 24.0°	95.2%
12	Reflections collected	5,238
13	Independent reflections	3,365 (R _{int} = 0.0361)
14	Reflections with $F^2 > 2s$	2,948
15	Structure solution	direct methods
16	Refinement method	Full-matrix least-squares on F ²
17	Data/restraints/parameters	3,365/454/327
18	Final R indices [F ² > 2s]	R1 = 0.0675, wR2 = 0.1892
19	R indices (all data)	R1 = 0.0775, wR2 = 0.1931
20	Goodness-of-fit on F ²	1.053
21	Largest and mean shift/su	0.005 and 0.000
22	Largest diff. peak and hole	1.50 and -1.05 e Å ⁻³

DABCO has a large influence on the incorporation of Ca2+ ions, since attempts to reproduce this structure with framework calcium, using a different organic template molecules, did not result in similar compounds being formed. Further to this an attempt was made to substitute nickel into this structure type instead of calcium. Nickel was chosen as this will form an octahedral coordination similar to that of calcium. Unfortunately this failed and only produced AIPO-5 instead. The bond length and angles for the other T atom sites are not shown; they are as we would expect for a tetrahedral system. The average AI-O tetrahedral bond length is 1.72Å and the average P-O bond length is 1.53Å. The average for the template C-C bond lengths is 1.47Å and the C-N 1.51Å. The differences in the template values form the ideal probably arise from the large amount of disorder in the template molecule.



Fig.14. Channel views of the DAF-7 structure. The calcium atoms are highlighted as green spheres

Table 6. Selected bond lengths and angles for DAF-7, highlighting

 the coordination geometry of the calcium and single aluminium

 site. Note the fifth Al-O bond is to a water molecule and not a

 framework oxygen

Atom Pair	Bond Length (Å)	Average Bond Angle	Degrees
Ca1 - O6	2.237(5)	O-Ca-O	90.93
Ca1 - O9B	2.343(5)		
Ca1 - O16	2.238(5)		
Ca1 - O18	2.397(5)		
Ca1 - O14	2.270(5)		
Ca1 - O17	2.375(5)		
A l 1 - O2	1.725(5)	O-Al-O	108.14
A l 1 - O8	1.721(5)		
A l 1 - O13C	1.743(6)		
A l 1 - O12B	1.726(5)		
A l 1 - O99w	2.257(19)	O-Al-Ow	76.46

4. Conclusions

In this paper two new framework structures have been presented, highlighting the importance of both the template species used in the synthesis and the choice of divalent cation to be substituted into the framework.

The synthesis routes followed in this research produced three distinct crystal morphologies, with three very different structures. The initial synthesis mixture contained 20% cobalt and small amounts of calcium salt, at this time an impurity, with DABCO as the template molecule. This mixture resulted in three types of crystal morphologies: blue rectangular crystals with the other two colourless but one rectangular and the other rhombohedral, later designated DAF-6 and DAF-7. The single-crystal study of the rectangular crystals (clearly seen as blue crystals in the optical microscope, whereas both DAF-6 and DAF-7 were colourless) revealed that this is similar to CoAIPO-34 or CoAIPO-44 (chabazite type); it is interesting to note that there is only one DABCO molecule present in the chabazite cage.

In order to confirm that some of the structures reported here are new, we performed the analysis involving the estimation of coordination sequence and comparing them with other known structures in

Table 7. Fractional Coordinates, occupancy and equivalent isotropic displacement parameters ($Å^2$) for as-prepared DAF-7

Atom	x	У	Z	Uiso
Ca(1)	0.64139(14)	2.30295(14)	0.64366(11)	0.0170(4)
AI(1)	0.7328(2)	1.9768(2)	0.42870(16)	0.0167(5)
AI(2)	1.42482(19)	1.66133(19)	0.85102(15)	0.0129(4)
A I (3)	0.97441(19)	1.52849(19)	0.67907(15)	0.0131(4)
P(1)	1.24411(17)	1.69196(17)	0.66350(14)	0.0138(4)
P(2)	1.31654(17)	1.58303(17)	1.12806(13)	0.0142(4)
P(3)	0.96142(17)	1.71683(16)	0.42894(13)	0.0131(4)
P(4)	0.53225(18)	1.96547(18)	0.68306(14)	0.0178(4)
O(1)	1.3173(5)	1.6469(5)	0.9948(4)	0.0197(10)
O(2)	0.8655(6)	1.8515(5)	0.3925(4)	0.0264(11)
O(3)	1.1004(5)	1.6121(5)	0.7072(4)	0.0201(10)
O(4)	0.8960(5)	1.6406(5)	0.5651(4)	0.0186(10)
O(5)	1.3123(6)	1.6450(6)	0.7703(4)	0.0300(12)
O(6)	0.5992(5)	2.0679(5)	0.7153(5)	0.0268(11)
O(7)	1.1671(5)	1.5159(6)	1.1918(4)	0.0298(12)
O(8)	0.6321(6)	1.9228(6)	0.5765(4)	0.0373(14)
O(9)	1.3481(5)	1.6591(6)	0.5580(4)	0.0282(11)
O(10)	0.9399(6)	1.6202(5)	0.3605(4)	0.0269(11)
O(11)	0.5005(7)	1.8275(6)	0.7892(4)	0.0409(15)
O(12)	1.2019(6)	1.8517(5)	0.6348(5)	0.0334(12)
O(13)	0.3887(6)	2.0280(7)	0.6519(5)	0.0408(14)

Atom	x	у	Z	Uiso
O(14)	0.6593(7)	2.3071(6)	0.8230(5)	0.0381(14)
O(15)	1.4323(7)	1.4612(8)	1.1404(5)	0.0521(18)
O(16)	0.8826(5)	2.2529(6)	0.5955(5)	0.0351(13)
O(17)	0.6191(6)	2.5581(5)	0.5818(5)	0.0310(12)
O(18)	0.3803(6)	2.3260(6)	0.6805(5)	0.0339(12)
O(99)	0.902(2)	1.985(2)	0.5222(17)	0.062(5)
N(1)	1.0971(9)	1.0933(9)	1.0080(7)	0.073(2)
C(2A)	1.2538(12)	1.0457(12)	0.9726(10)	0.029(3)
C(2B)	1.0820(12)	1.2504(11)	0.9473(10)	0.027(3)
C(2C)	1.0544(13)	1.0653(14)	1.1412(10)	0.044(3)
N(4)	1.2561(13)	1.2285(13)	1.0653(11)	0.060(3)
C(3C)	1.1462(16)	1.1434(17)	1.1755(10)	0.049(3)
C(3B)	1.1748(18)	1.3305(12)	0.9805(14)	0.062(4)
C(3A)	1.3475(12)	1.1250(17)	1.0062(14)	0.056(4)
N(4')	1.277(3)	1.152(3)	1.086(2)	0.059(4)
C(3B')	1.243(3)	1.289(2)	0.996(3)	0.053(6)
C(3A')	1.352(2)	1.047(3)	1.023(3)	0.064(7)
N(4")	1.187(3)	1.211(3)	1.134(3)	0.052(4)
C(3C")	1.023(3)	1.212(5)	1.164(3)	0.060(5)
C(3B")	1.290(4)	1.233(5)	1.012(3)	0.055(4)
C(3A")	1.225(5)	1.053(4)	1.166(3)	0.063(5)
C(2A")	1.148(4)	0.982(2)	1.116(3)	0.049(5)
C(2C")	0.975(3)	1.184(3)	1.070(3)	0.049(5)
C(2B")	1.228(4)	1.192(4)	0.933(2)	0.046(4)

the zeolite atlas, the program Kriber [22] was used. The analysis clearly revealed that the structure of the crystals with rectangular morphology is identical to that of Chabazite and the other two types are unique and new, thus justifying a new nomenclature.

The study also shows that template molecule choice is extremely important in this system and that the inclusion of the template molecule DABCO has a large influence on the incorporation of Ca²⁺ ions, since attempts to reproduce this structure with the framework-substituted calcium ions always failed when using some other organic template molecule. Also other divalent metals were tried in this synthesis, to replace the calcium in the framework; these also failed and produced only AIPO-5, suggesting a unique relationship between the calcium ions and the DABCO molecule in this synthesis.

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FIRST JACK-UP RIG LOAD-OUT IN VIET NAM

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Summary

This paper presents the design concept and operation results of load-out for the jack-up rig LTI model 116E built on two skid beams (without dry dock facilities). It was the first attempt to build a jack-up rig, almost completely, on two skid beams on the ground and load-out it using the submersible barge "Giant 2". The major characteristics of load-out structures, which depend on a jack-up rig configuration composed of general jack-up rig type hull and other structures, were its heavy weight of approximately 9,000 metric tons and long length of 74.09m compared to breadth and depth, i.e. x 62.79 x 7.95m. So, special consideration was required for safe load-out operation compared to previous load-out of other offshore structures (jackets, topsides) where the weight was less than 4,000 - 5,500 metric tons. The strength and longitudinal deflection of the jack-up rig were carefully analysed with appropriate weight distribution. All facilities for load-out including ground foundation, strain jack system and pulling system were designed based on the results of this analysis and the friction force between the skid way and hull supports (skid shoe). The ballasting operation for the barge was controlled by the control system (PLC) in the control room. Relative deflection in way of jack-up rig was monitored during the load-out operation. The motion of the jack-up rig during the load-out process, towing to float-off site and float-off phase were analysed and compared to model test results.

The load-out concept and methodologies described here are verified through the successful load-out operation of the first jack-up rig project in Viet Nam. The concept and experience gained can be adopted for the load-out design of extra-heavy structures where the weight is more than 15,000 metric tons. Guidelines for the development of an efficient construction method for offshore and ship type structures are also suggested for future application of this concept.

1. Introduction

Mobile & Floating types of offshore structures have shown a rapid overall increase in market share during the last several years in the offshore construction field. Generally, the fabrication and assembly of floating offshore structures, like Mobile Offshore Drilling Unit -Jack-up Rig (MODU), Tender Assist Drilling Barge (TAD), Floating Storage and Offloading system (FSO), Floating Production Storage and Offloading system (FSO), Floating Production Unit (FPU), semi-submersible and ships, have been carried out in the dry dock of a shipyard by stacking unit blocks sequentially from lower to upper levels.

In case of ship type of offshore structures, the lower hull or whole main hull fabrication and assembly are carried out in a dry dock as the conventional ship construction method and the topside/above main hull modules and legs sections are installed by a heavy lifting crane near the quay side. This method has great dependency on the dock schedule and tight fabrication process of the yard. So, it is very important to match the fabrication schedule between the remaining structural parts to meet the total project schedule. In such cases, it is difficult to incorporate any design change or modification required by the clients. On the other hand, if shipyard does not have a dry dock, they cannot do anything else.

The On-Ground Build Method applied to the 90m water depth Jack-up Rig Project is a new construction concept in Viet Nam for the above offshore structures in order to reduce the total construction schedule and have flexibility in the fabrication phase. The main hull and other structural parts are assembled on ground at the same time. The completed structure will be loaded-out and floated-off using submersible barges. This construction method requires the yard's experience including engineering capability of load-out and float-off operations to launch the completed structure.

This paper describes the design concept of the load out system and the operation results verified through successful operation.

2. Overview of load-out plan

2.1. Characteristic of jack-up rig 116E

The jack-up rig, the target structure of load-out, is composed of the main hull with the accommodation, cantilever with derrick above and three 74m long legs, weighing of about 9,020 metric tons lightweight. The rig's hull configuration is typically triangular shaped, with flat sides with two main longitudinal bulkheads at 7.9m centreline offset. The principal dimension of jack-up is summarised as follows:



Fig.1. Jack-up Outboard Profile



Fig.2. Jack- up Overall Plan

- Length (overall): 74.09m;
- Breadth (molded): 62.79m;
- Depth (molded): 7.95m;
- Design Draft (molded): 5.0m;
- Light weight: 9,020 metric tons.

2.2. Yard layout and load-out plan

Generally, the assembly location of the load-out structure is decided by considering the weight of the

structure (line load) and the water depth adjacent to quay side for mooring of the load-out submersible barge. Fig.3 shows the general arrangement of the loadout system, such as the skid way, strain jack & pulling system, the load-out submersible barge and the jetty.

3. Load-out system design basis

Various static, dynamic loads and other limitations that were considered during the design of the load-out system are detailed below.

3.1. Static loads

Light weight including 10% margin and friction force is considered as the static load for design of the load-out system.

More than 1/3rd of jack-up total length (74.09m) is supported by two skid beams arranged on two (2) skid ways in way of the jack-up area.

The friction force between the skid way and the skid shoe can be calculated by multiplying the weight and friction coefficient. The contact materials between the skid shoe and skid beam are fluoroslip skid way plate (FL 415 PTFE) and 20% static (breakout) friction coefficient was applied for the contact material. This leads to conservative design of load-out

systems. A 12% dynamics (sliding) friction coefficient was observed at break out condition during the actual operation [9, 11].

3.2 Dynamic loads

Environmental forces, such as wind, wave and current, influence the motion of the load-out semisubmersible barges and, consequently, the dynamic load to load-out system. Estimation of the barge motion and wave bending moment is very important to the design of the load-out system. Table 1 shows the environmental conditions for load-out operation of the jack-up rig 116E [3].

Table 2 is the summary of motion analysis result (using MOSES software). This result was verified through model tests in a towing tank.



Fig.3. Jack up Load-out Plan

3.3. Other limitations

There are various limitations to be considered during load-out design depending on the load-out facilities, characteristics of the load-out structure and the yard ground conditions. The following limitations were considered in jack-up rig load-out design.

- Hydraulic jack capacity and maximum stroke;
- Pulling jack capacity and speed;
- Strength and deflection of jack-up structure;
- Ballasting capacity and speed of load-out barges;
- Strength of load-out barges including fender;
- Capacity of ground and jetty;
- Other load-out facilities of the yard.

4. Load-out system design

This section presents design viewpoints of the load-out system, the required analysis items and results considering given design conditions described in the previous section. The jack-up rig structure was assembled as supported by temporary supports during the fabrication phase.

4.1. Skid way on ground and barge

The skidding method, which is the general method for load-out of offshore structures, was applied for jack-up rig load-out. Two skid beams on the ground and on the barges were designed to support the skid shoes and jack-up rig, i.e side shell, transverse bulkheads and longitudinal bulkheads. The surface of the skid beam was made of special material to reduce friction force (fluoroslip skid way plate - FL 415 PTFE).

Each skid beam on the ground skid way was supported by rigid foundation consisting of concrete mat and pile foundation for the ground skid way, and grillage beam foundation for the barge skid way. These foundations should be designed not to settle down beyond the jack stroke limitation.

4.2. Jetty stability analysis

Jetty stability should be verified in an early stage of load-out design by checking various

failure modes considering the expected load conditions. The jetty is analysed for the following loads:

- Line load due to weight distribution;

- Pulling force caused to pressure load in front of the quay.

- Barge berthing/mooring load.

The safety of the jetty is mainly

related to the line load applied during the load-out process. So, the load-out system should be designed to minimise the line load as much as possible and the calculated safety margin of the jetty should be sufficient considering uncertainty.

4.3. Load-out barge and ballasting plan

The following factors are to be considered while selecting the load-out barge:

- Dead weight considering berthing draft;

- Deck area to accommodate required active shoe length;

- Ballasting speed considering pulling speed;
- Longitudinal strength and deck local strength;
- Float-off stability.

The semi-submersible barge "Giant 2" of Smit Division was selected considering the above requirements. A 14-step ballasting plan was prepared for the load-out process. The ballasting status and relative deflection were monitored during the load-out operation [4].

4.3.1. Principal Dimensions of "Giant 2"

The principal dimensions of the load-out barge (Giant 2) are summarised as follows:

- Length (overall): 140m;
- Breadth (molded): 36m;
- Depth (molded): 8.5m;
- Submerged draft: 6.68m;
- Dead weight: 24,000 metric tons;

- Classification LR, 100A1 semi-submersible ocean going transportation barges, 1966.

Environmental condition	Wind (knots)	Wave Hs (m)	Wave Tz (sec)	Current (Knots)	Tide (m)				
	20	0.6	3	1					

Table 1. Environmental condition for load-out

Table 2. Maximum motion & Acceleration

Hs = 0.6m	Surge	Sway	Heave	Roll	Pitch	Yaw	
Tz = 3s	[m], [m/s²]			[deg], [deg/s ²]			
Displacement							
Accelerations	0.09	0.39	0.40	0.24	0.24	0.12	

4.3.2. Ballasting control

The ballasting control should be performed to keep the barge draft, trim and heel within operational limits, which are ± 0.25 degree for trim and ± 0.2 degree for heel. The ballasting was divided to fourteen steps for approximately 6m moving distance. Also the ballasting plan includes estimated ballasting time due to moving speed in relation to the pulling jack speed & tide table. The actual ballasting status during load-out was monitored by measuring the draft from draft gauge and by theodolite.

In order to control the "Giant 2" barge draft, trim and heel condition during the load transfer and also to compensate ballasting due to tide variation, external pumps independent of the main ballasting system were installed and operated to the barge internal pumping system. The capacity of external pumps and selection of tank were decided considering the tide variation rate and the variation rate of barge displacement. Twenty-four Nos. 10 PS submersible pumps were provided, with each pump capable of 800m³/hr [2].

4.4. Analysis of jack-up rig strength and deformation

The safety of load-out structure should be verified by 3-D FEM analysis (using ANSYS and SACS software). The stress ratio, plate buckling capacity, and deformation should be checked against actual line load related to hydraulic jack load.

The analysis results showed that the jack-up structure had sufficient safety during the load-out operation. In addition, stress ratio and deformation values were less than those of the in-place condition. The maximum von-mises stress was found as 180N/mm² in way of side shell plate near the mid ship bottom area and maximum Z-deflection was 120mm in way of the supporting region of the hydraulic jacks. This natural deformation should be maintained by jack stroke during the load-out operation



to control the load-o system using strand jaof experience of previo The pulling jack sy strand jacks, with nom tons each, installed at support, a fixed ancho

> and fixed anchor. Skidding of the load-out structure was done by operation of strand jacks. A strand jack, which has 441.5 tons pulling capacity (max PPU pressure 350 bar), 500mm stroke and 12m/hour pulling speed, was used for jack-up rig load-out [1, 4]. The jack capacity was designed to exceed 115% of the estimated friction force in order to cover any unexpected increase in friction. The components in the load-out system design such as link beam, steel fender and skid way, which are subject to pulling force, should be designed

considering the total pulling capacity.

4.6. Fender

Steel fenders were used for linking each ground skid way to the barge. These two linking facilities supported line load and total pulling force, respectively. Fig.2 - 3 shows the arrangement of the linking systems.

Steel fenders installed between the front wall of the quay and the transom of the barges took compression force due to the pulling operation. The

Fig.5. Plate Stresses for loadcase 1 and loadcase 2

7.5

so as not to cause local concentration of loads. A shimming plate should be designed that can keep the deformation of jack-up within limits in case of active jack failure. The deformation of the load-out barge due to still water and wave bending moment should be considered in the total deformation, which is covered by the jack stroke. Fig.2 shows the combined stress plot and Fig.4 shows the deformation during load-out condition [16, 17].

4.5. Pulling jack system

The required pulling force for the load-out structure increases linearly with the increase of friction force. For the jack-up rig load-out, the required pulling force was about 1,808.4 tons considering a 20% static friction coefficient. The pulling system should be designed to be able to control the load-out direction. Typical pulling system using strand jacks was adopted on the basis of experience of previous load-out projects.

The pulling jack system had six (06) Nos. G-SJ27 strand jacks, with nominal pulling capacity of 441.5 tons each, installed at the end of the hydraulic jack support, a fixed anchor welded to load-out barge deck, and strand wire connecting the strand jack and fixed anchor. Skidding of the load-out structure was done by operation of strand jacks. required berthing area per fender was about 1.5m by 4.5m as derived from the quay stability analysis result. The barge transom structure was checked to determine whether it had sufficient strength against pulling compression. The fender itself was designed to resist pulling compression and 20% of lateral force considering the barge movement.

4.7. Mooring system

"Giant 2" was moored at the quayside throughout the load-out operation. The mooring lines were designed to keep the barge position based on technical guidance (against a 10-year return environmental condition) as shown on Table 1. The maximum mooring force was approximately 29.49 tons due to a wide wind area that had never been experienced. The most critical condition in mooring design was the condition after load-out. In this case, the total force had to be resisted by the mooring lines only. Emergency mooring activities were prepared considering a sudden occurrence of a typhoon based on 100-year storm condition [8]. In this case, the link beams were fastened to take the role of a mooring line and also additional mooring lines were required.

4.8. Monitoring system

Points of concern which might disturb operation were listed and monitored continuously during load-out. These data were compared with estimated values and verified to keep within the limit. The main items to be monitored are listed bellows.

- Hull deflection level;
- Ground settlement;
- Load-out moving direction;

- Hydraulic jack pressure & stroke;
- Pulling jack load;
- Barge draft level & positioning;
- Relative deflection of barge connection frame.

5. Points of concern for operation

All expected risky items raised in the design phase through HAZOP should be carefully monitored and controlled during actual operation. Because of the characteristics of the load-out structure in case of the jack-up rig, there many points to be considered as follows:

- Controlling the skidding direction due to the huge length of the load-out structure;

- Even distribution of excessive pulling force to quay wall;

- Strength verification in way of barge connectors from measured data.

Excessive pulling force, barge connection, and control of "Giant 2" are highlights of jack-up rig load-out operation.

6. Conclusion

The design methodology described in this paper contributed to the successful load-out operation of Vietnam's first on-ground build jack-up rig. The paper suggests a new construction methodology in Viet Nam that is different from the conventional dry dock construction of floating offshore structures, such as jackup rig, TAD barge, FPU, FPSO, semi-submersible, and drilling ship, applicable in the near future.

Environment divertien	Maximum line tension (tons)							
Environment direction	P1	P2	P3	S1	S2	S3		
From Stern	18.18	27.39	27.65	16.20	21.57	25.00		
From Stbd Quarter Stern	9.07	11.12	9.85	5.76	6.40	13.86		
From Stbd	6.83	9.94	27.31	7.72	11.60	29.49		
From Stbd Quarter Bow	6.97	7.77	14.10	9.50	9.71	9.99		
From Bow	5.52	5.89	6.61	5.21	5.36	5.81		
From Port Quarter Bow	9.98	11.48	12.39	6.68	6.37	13.15		
From Port	8.06	11.47	31.77	6.79	9.85	27.49		
From Port Quarter Stern	6.45	7.95	14.99	8.36	9.10	8.05		
Maximum	18.18	27.39	31.77	16.20	21.57	29.49		
Line Tension Criteria < 32.2 tons (for P1, P2, S1, S2) < 37.4 tons (for P3 & S3)	ОК	ОК	ОК	ОК	ОК	ОК		

Table 3. Mooring Line Tension checking results



Fig.6. Semi-submersible Barge Mooring Arrangement

This construction method can allow major work for commissioning to be completed on the ground. It will provide a more convenient working environment than conventional construction methods in view of the service of good facilities such as cranes, accessibility and multiple-working.

This construction method can also be applied to conventional ship construction to reduce the assembly schedule and increase efficiency even without a dry dock since this method indicates the possibility of load-out and float-off of large floating offshore structures and ship blocks to be finally mated in the sea.

Above all, this paper will provide the design basis and experience gained to develop load-out methodology of huge size structures such as Mega Float and Barge Mounted Plant (BMP), which cannot be accommodated in the present dry dock facility of a shipyard.

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A platform in Indonesia that collapsed due to a ship collision [1]

ASSESSMENT OF PROBABILITY OF FAILURE OF STEEL JACKET STRUCTURES SUBJECT TO SHIP COLLISION IN OFFSHORE VIET NAM

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Summary

The paper presents a reliability approach to assess the impact of ship collision on the existing jacket platforms in the waters of Viet Nam. The approach adopts the limit state concept for boat impact energy and platform structural absorption energy capacity to assess the structural failures. Two boat impact energy spectra, representing the 50th and 95th percentiles of impact energy, are used to determine the probability of platform structural failure. In this paper, the platform structural absorption energy of one representative steel jacket type platform is determined using SACS "Collapse" module based on plasticity for structural members which will subsequently contribute to the loss of global structural stiffness.

The study provides an insight into the maximum boat impact energy for steel jacket type platforms which can be mitigated by other means such as regulation of structural design criteria and marine operations.

1. Introduction

The recent Bombay High disaster and the collision of a boat with a braced monopod platform located offshore Madura island in Indonesia have alerted Operators in Southeast Asia to the need for assessment of the marine operation safety of their offshore installation. The above kind of disaster has previously been experienced by Operators in the North Sea and the Gulf of Mexico as recorded and studied by HSE [12].

The study was based on the incident reports from 1975 to 2001 for passing and attendant vessels indicating that the frequency of incidents per year for fixed installations was 6.3% resulting in moderate or severe damage per year of 0.95% of total vessel collisions.

Efforts to minimise the installation vessel collision and damage rates were made by implementing more stringent marine operation regulations and structural means of providing higher structural absorption energy. In response to structural safety requirements, researchers have explored ways of enhancing the structural absorption energy emphasising structural nonlinear geometrical and material nonlinearity [3 - 9] including pipe dent mechanism, which eventually merged into Codes and Regulations [2, 10, 11].

2. Development of Vessel Motion Energy Model

Both Code and Guidance [2, 9] recommended the vessel impact energy " E_v " is expressed as the product of vessel motion energy in free field times a relative mass-velocity factor representing the installation flexibility and mass. The vessel impact energy " E_v " is determined by the following equation:

$$E_{V} = E_{S} + E_{I} = \left(\frac{1}{2}(M_{s} + M_{sa})V_{s}^{2}\right) \left(\frac{\left(1 - \frac{V_{i}}{V_{s}}\right)^{2}}{1 + \frac{M_{s} + M_{sa}}{M_{i} + M_{ia}}}\right)$$
(1)

Where $E_{s'}$, $E_{t'}$, $M_{s'}$, $M_{sa'}$, M_{μ} , $M_{a'}$, V_s and V_{μ} are ship energy absorption; installation (structural) absorption energy; ship loaded displacement mass; ship added mass based on stern collision; effective installation mass; installation added mass; ship free-field velocity and installation induced velocity, respectively.

The vessel motion energy representing the first term in brackets on the RHS of Eq.(1) is statistically conducted using data of available sixteen attendant vessels as shown in Table 1.

No	Vessel Name	Vessel Types	Overall Length (m)	Breadth (m)	Depth (m)	Draft (P100) (m)	DWT (P100) (Mtons)
1	AHTS-Bourbon Liberty 219	Anchor Handling Tug Supply	59.78	15.00	5.50	4.30	1460.00
2	AHTS-Seacor Valor	Anchor Handling Tug Supply	67.00	14.00	6.00	5.00	2198.00
3	Jaya Amandam	Anchor Handling Tug Supply	58.70	14.60	5.50	4.75	1350.00
4	Mary K	Anchor Handling Tug Supply	59.00	14.60	5.50	4.50	1275.00
5	Sapa	Anchor Handling Tug Supply	64.40	13.80	6.90	5.88	1950.00
6	Bourbon Liberty 118	Support Vessel	57.90	14.00	5.50	4.90	1509.00
7	Thanh Long	Anchor Handling Tug Supply	81.16	16.30	7.20	4.90	1382.00
8	Greatship Ahalya	Towing & Supply Vessel	63.00	15.00	6.10	5.20	1600.00
9	Binh Minh	Anchor Handling Tug Supply	61.00	14.95	5.80	4.80	1500.00
10	Visal 2	Towing & Supply Vessel	53.34	11.58	4.57	3.81	343.00
11	Visal Sai Gon	Towing & Supply Vessel	64.40	13.80	6.90	5.90	1875.00
12	FALCON 06	Multipurpose tug boat	34.00	9.93	4.60	3.70	268.20
13	Dau Khi 101	Utility Standby Vessel	50.06	11.62	3.50	2.62	606.75
14	Dau Khi 105	Utility Standby Vessel	39.00	9.50	3.21	1.70	479.16
15	Dau Khi 106	Utility Standby Vessel	50.03	11.58	4.26	2.16	678.00
16	Phu My 06	Support Vessel	50.60	11.50	3.96	3.40	467.00

 Table 1. Vessel Particular Data

This minimum information is used to statistically develop a vessel motion energy model for the structural assessment of fixed steel jacket platforms against vessel collision in the Vietnamese waters. Some fundamental assumptions are set for 50th percentile data such as for loaded displacement based on 80% DWT and for economic vessel speed. These vessel loaded displacement values inherit a variation of 10% as the lightship weights

are not available but the prediction is based on block coefficient for this type of supply vessel. Furthermore, the cruising and maximum vessel speeds are considered as the 80th and 100th percentiles, respectively, by which together with the P50 vessel speed, the vessel speed probability distribution model using three-parameter Weibull Distribution is generated as shown in Tables 2 and 3, where location parameter γ is not shown.

		Vs	Vs	Vs	Weibull Distribution				
No	Vessel Name	(Knots) (P50)	(Knots) (P80)	(Knots) (P100)	Beta (β)	Alpha (α)	Std (σ)	Vessel Types	
1	AHTS-Bourbon Liberty 219	9.00	12.00	13.00	3.05	10.20	0.326	AHT Supply Vessel	
2	AHTS-Seacor Valor	10.00	11.00	13.00	8.00	10.35	0.844	AHT Supply Vessel	
3	Jaya Amandam	10.00	10.90	13.50	8.00	10.45	0.836	AHT Supply Vessel	
4	Mary K	10.00	11.10	13.00	8.00	10.45	0.836	AHT Supply Vessel	
5	Sapa	10.00	12.00	15.00	6.00	10.70	0.613	AHT Supply Vessel	
6	Bourbon Liberty 118	10.50	11.50	12.50	9.00	10.90	0.903	Support Vessel	
7	Thanh Long	9.00	10.00	13.00	7.00	9.35	0.814	AHT Supply Vessel	
8	Greatship Ahalya	9.00	11.00	13.50	4.20	9.80	0.467	Towing Supply Vessel	
9	Binh Minh	10.00	12.00	13.70	4.70	10.80	0.476	AHT Supply Vessel	
10	Visal 2	9.50	10.65	12.00	7.40	9.95	0.811	Towing Supply Vessel	
11	Visal Sai Gon	8.00	9.00	12.00	7.00	8.40	0.901	Towing Supply Vessel	
12	FALCON 06	10.00	10.60	12.00	10.20	10.35	1.076	Multi-purpose tug boat	
13	Dau Khi 101	6.50	7.65	9.50	5.50	6.94	0.848	Utility Standby Vessel	
14	Dau Khi 105	6.50	7.65	9.50	5.50	6.94	0.848	Utility Standby Vessel	
15	Dau Khi 106	7.50	9.50	12.50	3.70	8.30	0.482	Utility Standby Vessel	
16	Phu My 06	9.50	10.65	13.00	7.40	9.95	0.811	Support Vessel	

Table 2. Weibull Distribution Parameters for Vessel Speeds

Table 3. Weibull Distribution Parameters for Vessel Motion Energy

No	Vessel Name	EV (MJ) (P50)	σΕν	Alpha	Beta	Gama
1	AHTS-Bourbon Liberty 219	28.39	2.03	3.05	10.20	19.30
2	AHTS-Seacor Valor	41.52	7.09	8.00	10.35	31.63
3	Jaya Amandam	37.52	6.09	8.00	10.45	27.52
4	Mary K	35.75	5.80	8.00	10.45	25.76
5	Sapa	47.58	5.74	6.00	10.70	37.50
6	Bourbon Liberty 118	39.80	6.75	6.75 9.00		29.30
7	Thanh Long	50.03	8.50	7.00	9.35	41.16
8	Greatship Ahalya 36.74		3.70	4.20	9.80	25.78
9	Binh Minh 40.21		3.73	4.70	10.80	30.20
10	Visal 2	20.62	3.24	7.40	9.95	11.15
11	Visal Sai Gon	27.84	6.20	7.00	8.40	19.87
12	FALCON 06	11.90	2.41	10.20	10.35	1.91
13	Dau Khi 101	6.31	1.62	5.50	6.94	0.00
14	Dau Khi 105	2.35	0.67	5.50	6.94	0.00
15	Dau Khi 106	6.10	0.81	3.70	8.30	0.00
16	Phu My 06	16.91	2.73	7.40	9.95	7.44

Taking the upper-bound values of P50 vessel motion energy, the vessel motion energy model can be developed as shown in Fig.1.



Fig.1. Vessel Motion Energy Model based on P50

3. Development of Vessel Impact Energy Model

In view of Eq.(1), it can be seen that the factor is specific depending on the installation mass and added mass as well as the installation velocity during collision. This installation velocity is related to platform structural stiffness and pipe dent stiffness at the hit point. Platform structural absorption energy model can be developed using a number of platform structural data for the specific location.

In reference to the same impact force acting at the jacket tubular legs or braces causing the tubular displacement and pipe dent, the following equation can be derived as:

$$\delta_D = \frac{\left(a\Delta^2 + b\Delta + c\right)\Delta t^3}{P^2} \left(\frac{21F_Y}{4}\right)^2 \tag{2}$$

$$\delta_{D} = \frac{\left(a\Delta^{2} + b\Delta + c\right)\Delta t^{4}}{P^{2}D} \left(\frac{150F_{\gamma}}{4}\right)^{2}$$
(3)

Where: Δ , $\delta_{D'}$, P, D, t, F_{y'}, a, b and c are joint displacement of hitting point; pipe denting; impact force; pipe diameter; pipe wall thickness; mean yield stress; pipe flexural stiffness parameters and stiffness constant, respectively. The flexural stiffness parameters and constant are determined using the stress analysis of platform structure due to impact energy applying at the hitting point.

Eq.(2) based on Amdahl's impact force for pipe dent [6] holds for D/t ratio of pipe less than 50, while Eq.(3) which is based on Ellinas and Walker work [6] for D/t ratio of pipe greater than 50. When the ship absorption energy is assumed to be zero, and the installation flexural absorption energy is modelled as a polynomial function of power two, the vessel impact energy is equal to the installation absorption energy which is contributed by tubular flexural and pipe dent mechanism. The following expression for ship and installation absorption energy holds true for any deformations of ship and installation:

$$E_{V} = E_{S} + E_{I} = \frac{7F_{y} \left(\delta_{D} t\right)^{\frac{3}{2}}}{2} + \left(\frac{a\Delta^{4}}{4} + \frac{b\Delta^{3}}{3} + \frac{c\Delta^{2}}{2}\right)$$
(4)

$$E_{v} = E_{s} + E_{I} = \frac{25F_{v}\left(\delta_{D}\right)^{\frac{3}{2}}t^{2}}{D^{\frac{1}{2}}} + \left(\frac{a\Delta^{4}}{4} + \frac{b\Delta^{3}}{3} + \frac{c\Delta^{2}}{2}\right)$$
(5)

The installation velocity in Eq.(1) can be approximated from the dynamic response of installation (platform structure) at the hit point as shown below:

$$V_I \cong \omega_1 \left(\Delta + \delta_D \right)$$
 (6)

Where:

V₁: Velocity of platform (cm/s);

 ω_1 : Structure frequency at first mode from Eigenvalue analysis;

 Δ : Impacted joint displacement at first mode (cm);

 δ_{D} : Dent depth (cm).

By performing an iterative calculation using Eqs.(2 -6), the impact force, the pipe dent, the joint displacement tubular leg or brace, the installation (structural) velocity and vessel impact energy can be determined.



Fig.2. Vessel Impact Energy Model

With the same method based on probability density function (pdf) of vessel impact energy P95, the vessel impact energy model P95 can be found. Combine two Vessel Impact Energy Models (P50 & P95) with 20% denting plus associated bending energy, with the result expressed as in Fig.2.

Standard deviation of vessel impact energy $\sigma_{_{EV}}$ can be expressed as Eq.(7):

$$\sigma_{EV} = \sqrt{\left(\frac{\partial E_V}{\partial M}\sigma_M\right)^2 + \left(\frac{\partial E_V}{\partial V}\sigma_V\right)^2 + \left(\frac{\partial E_V}{\partial f}\sigma_f\right)^2} \tag{7}$$

Where: $\sigma_{_{M'}} \sigma_v$ and σ_f are standard deviations of vessel loaded displacement; vessel velocity and relative mass-velocity factor, respectively

4. Structural Failure Criteria

The adopted structural criteria may vary from one company to another depending on the target risk level acceptable to the company. In this study, the local surrounding structural member failure is limited to plastic hinges and depth of pipe dents developed on the collided structural member, while the global structural inelastic response behaviour is taken into account based on plastic hinges on the surrounding collided structural member.

In reference to API RP 2A LRFD [13], where the nominal bending stress is replaced by the mean yield strength $F_{y'}$ the following failure criteria for structural members under combination of tension with bending moment in Eq.(8) and of compression and bending moment in Eqs.(9 - 10) can be expressed as below:

$$\Gamma = -\cos\left[\frac{\pi}{2}\left(\frac{f_t}{F_y}\right)\right] + \left[\left(\frac{f_{by}}{F_y}\right)^2 + \left(\frac{f_{bz}}{F_y}\right)^2\right]^{1/2} \le 0$$
(8)

$$\Gamma = -\cos\left[\frac{\pi}{2}\left(\frac{f_c}{F_{xc}}\right)\right] + \left[\left(\frac{f_{by}}{F_y}\right)^2 + \left(\frac{f_{bz}}{F_y}\right)^2\right]^{1/2} \le 0 \qquad (9)$$

$$\Gamma = \frac{f_c}{F_{xc}} + \left[\left(\frac{C_{my} f_{by} / F_y}{\left(1 - \frac{f_c}{F'_{ey}} \right)} \right)^2 + \left(\frac{C_{mz} f_{bz} / F_y}{\left(1 - \frac{f_c}{F'_{ey}} \right)} \right)^2 \right]^{-1} \le 0$$
 (10)

Where the notation in Eqs.(8 - 10) can be referred to API RP 2A LRFD, 1993.

If the ratio of compressive stress to member buckling stress is over 0.15, the Eq.(10) can be used instead of Eq.(9).

The pipe dent criteria is based on maximum dent depth to diameter ratio or maximum allowable dent depth such as annulus width of ungrouted jacket leg in order to satisfy the applicability of the dent pipe formulations. DNV [11] stipulated 20% of diameter as the failure criteria for pipe denting, by which the pipe dent absorption energy can be expressed in Eqs.(11 - 12):

$$(E_D)_{\rm max} = 2.236F_v Dt^2$$
 (11)

$$(E_D)_{\rm max} = 0.313 F_y (Dt)^{1.5}$$
 (12)

Where:

(E_D)_{max}: Maximum dent energy;

D: Pipe diameter;

t: Pipe thickness.

5. Structural Absorption Energy

To determine the structural bending energy of a steel jacket platform, an integrated pile-jacket and topside structural model is developed using SACS software package as shown in Fig.3. To do so, a non-linear progressive analysis is adopted and performed by SACS - Collapse module, with failure criteria of structural members limited to the development of plastic hinges [14].

The computed structural bending (flexural) energy using non-linear progressive analysis takes into account the global flexibility of integrated jacket-topside with pile and local structural absorption energy of both collided and surrounding members. The pipe denting energy is computed based on Amdahl formula [6] for diameter to



Fig.3. Step 31-Plastic Hinges members occur

thickness ratio less than 50, otherwise Ellinas & Walker formula is applied. The result is shown in Fig.4.

Fig.4 shows a specific structural bending and pipe denting energy for a particular steel jacket type platform in the Vietnamese waters. No detailed FEM is conducted to investigate the local pipe denting deformation, except by implementing the dent depth only Eqs.(2 - 3). The interaction between the structural stiffness of the global structure and pipe dent is represented using a series system of interaction by maintaining the same impact force at the structural member and pipe dent point.



Fig.4. Structural bending and pipe denting absorption energy

6. Probability of Structural Failure

The probability of failure P_f for the damage of a collided tubular brace or jacket leg can be determined using the limit state function (Z) which is described by the fault tree diagram below:



Fig.5. Boolean algorithms to assess the probability of structural member damage

The above representation can be expressed with the equation below:

$$Z = E_{I} - E_{V} = (E_{B} + E_{D}) - E_{V}$$
(13)

$$\sigma_Z = \sqrt{\left(\sigma_B^2 + \sigma_D^2\right) + \sigma_V^2} \tag{14}$$

Where: E_{B} and E_{D} are structural bending absorption energy and pipe denting energy respectively, as shown in Fig.4.

From Eq.(13), the probability of failure P_f is defined when Z < 0.

Based on the above theory the probability of structural failure P_f caused by ship impact is determined as the area of cross section shown in Fig.6.



Fig.6. Probability of structural failure P_f caused by ship impact

Where:

E_f Required structural bending and pipe denting absorption energy, is presented as Fig.2, section 3 of this account.

7. Conclusions

With minimum vessel particulars and operational data, the study can present only preliminary findings on boat kinetic (motion) energy and probability of failure of a collided platform structure. Nevertheless, the presented approach can still be used as a guideline for the structural assessment of a boat collision against a jacket leg and braces. The findings can be refined by updating the study using more data concerning vessel particulars and platform structures.

The study shows that based on failure criteria of 20% dent depth ratio and local plastic failure of collided member, the probabilities of failure of the collided jacket leg are approximately 10% for mean vessel speed and 57% for P95 vessel speed, respectively. These findings indicated more than 50% of jacket legs will fail if collided by P95 vessel speed and about 10% for collision due to mean vessel speed.

Furthermore, the findings also provide insight for Operators in the Vietnamese waters on boat impact energy criteria for designing jacket legs, braces and boat landings due to accidental loads, besides implementing marine operation regulations. Further studies on failure risk, economical aspects and mitigation means are therefore recommended to meet target acceptance criteria based on acceptable risk levels.

8. Appendices

8.1. Interpretation of symbols



⁽¹⁾, ⁽²⁾ - P50 and P95

$$P50 = P(0 < x < x_{50}) = \int_0^{x_{50}} f(x) dx$$
$$P95 = P(0 < x < x_{95}) = \int_0^{x_{95}} f(x) dx$$

Random Variable x - Velocity of Vessel

Cumulative Distribution Function $F(x) = \int_0^{\infty} f(x) dx$ Probability Density Function f(x) of a Weilbull distribution.



Fig.7. Cumulative distribution and probability density function

8.2. Summary of results extracted from SACS Version 5.3

Load Step	Load Cond	Load Factor	Joint/member/plate	Length (m)	Subseg	Plasticity	Event
19	500	36	BI01 L103	0.000	1	0.167	Plastic
19	500	36	L203 BI01	8.100	9	0.083	Plastic
20	500	38	152 L103	3.193	9	0.083	Plastic
21	500	40	180 130	0.000	1	0.083	Plastic
21	500	40	BI01 L103	0.545	2	0.083	Plastic
21	500	40	L203 BI01	6.954	8	0.083	Plastic
21	500	40	LI01 P103	0.000	1	0.167	Plastic
21	500	40	P303 LI01	12.047	8	0.167	Plastic
22	500	42	152 L103	2.761	8	0.083	Plastic
23	500	44	202 L103	9.163	9	0.083	Plastic
23	500	44	BI01 L103	0.000	1	0.333	Plastic
23	500	44	L103 180	0.000	1	0.167	Plastic
23	500	44	L203 BI01	5.808	7	0.083	Plastic
23	500	44	L203 BI01	8.100	9	0.333	Plastic
23	500	44	LI01 P103	0.578	2	0.167	Plastic

Table 4. Special Event History Report (summary)

Load Step	Load Cond	Load Factor	Joint/member/plate	Length (m)	Subseg	Plasticity	Event
23	500	44	P303 Ll01	10.326	7	0.083	Plastic
24	500	46	152 L103	2.329	7	0.167	Plastic
24	500	46	152 L103	3.193	9	0.333	Plastic
24	500	46	180 106	0.830	2	0.083	Plastic
24	500	46	180 130	0.649	2	0.167	Plastic
24	500	46	L103 180	0.079	2	0.083	Plastic
24	500	46	LI01 P103	0.000	1	0.333	Plastic
24	500	46	P303 L I 01	12.047	8	0.333	Plastic
25	500	48	152 L103	1.897	6	0.083	Plastic
25	500	48	202 L103	7.886	8	0.083	Plastic
25	500	48	BI01 L103	0.545	2	0.333	Plastic
25	500	48	BI01 L103	1.089	3	0.167	Plastic
25	500	48	L103 180	0.159	3	0.083	Plastic
25	500	48	L103 180	0.556	8	0.083	Plastic
25	500	48	L203 BI01	6.954	8	0.333	Plastic
31	500	60	106 105	8.266	8	0.333	Plastic
31	500	60	106 130	2.968	5	0.167	Plastic
31	500	60	106 130	3.710	6	0.250	Plastic
31	500	60	106 130	4.452	7	0.583	Plastic
31	500	60	106 130	5.194	8	0.750	Plastic
31	500	60	107 106	0.000	1	0.333	Plastic
31	500	60	107 106	0.300	2	0.167	Plastic
31	500	60	107 106	0.600	3	0.750	Plastic
31	500	60	107 106	1.120	4	0.667	Plastic
31	500	60	107 106	1.640	5	0.583	Plastic
31	500	60	107 106	2.160	6	0.333	Plastic
31	500	60	107 106	2.681	7	0.250	Plastic
31	500	60	108 W100	0.000	1	0.917	Plastic
31	500	60	108 W100	0.046	2	0.917	Plastic
31	500	60	108 W100	0.092	3	0.917	Plastic
31	500	60	108 W100	0.138	4	0.833	Plastic
31	500	60	108 W100	0.183	5	0.833	Plastic
31	500	60	108 W100	0.229	6	0.833	Plastic
31	500	60	108 W100	0.275	7	0.833	Plastic
31	500	60	108 W100	0.321	8	0.833	Plastic
31	500	60	115 W100	0.000	1	1.000	First hinged occurs

	Loa	ad		Str	ucture		Ship		Total	
Step	Cond	Factor Joint	Work X	Work Y	Work Z	Total	Stern	Broadside	Stern	Broadside
1	BI	1.00 B I 01	1.25	5.02	0.00	6.27	0.00	0.00	6.27	6.27
1	BI	Sum Joints	1.25	5.02	0.00	6.27	0.00	0.00	6.27	6.27
2	500	2.00 BI01	10.31	28.27	0.00	38.58	0.00	0.00	38.58	38.58
2	500	Sum Joints	10.31	28.27	0.00	38.58	0.00	0.00	38.58	38.58
3	500	4.00 B I 01	27.52	57.85	0.00	85.37	0.00	0.00	85.37	85.37
3	500	Sum Joints	27.52	57.85	0.00	85.37	0.00	0.00	85.37	85.37
4	500	6.00 B I 01	52.88	93.76	0.00	146.64	0.00	0.00	146.64	146.64
4	500	Sum Joints	52.88	93.76	0.00	146.64	0.00	0.00	146.64	146.64
5	500	8.00 B I 01	86.4	136	0.00	222.39	0.00	0.00	222.39	222.39
5	500	Sum Joints	86.4	136	0.00	222.39	0.00	0.00	222.39	222.39
6	500	10.00 B l 01	128.08	184.58	0.00	312.65	0.00	0.00	312.65	312.65
6	500	Sum Joints	128.08	184.58	0.00	312.65	0.00	0.00	312.65	312.65
7	500	12.00 B I 01	177.93	239.51	0.00	417.44	0.00	0.00	417.44	417.44
7	500	Sum Joints	177.93	239.51	0.00	417.44	0.00	0.00	417.44	417.44
8	500	14.00 B I 01	235.93	300.77	0.00	536.71	139.26	16.61	675.96	553.32
8	500	Sum Joints	235.93	300.77	0.00	536.71	139.26	16.61	675.96	553.32
9	500	16.00 B l 01	302.05	368.32	0.00	670.37	481.55	190.87	1151.92	861.24
9	500	Sum Joints	302.05	368.32	0.00	670.37	481.55	190.87	1151.92	861.24
10	500	18.00 B I 01	376.21	442.12	0.00	818.33	858.79	382.92	1677.13	1201.25
31	500	Sum Joints	3620.3	3300.86	0.00	6921.16	447587.12	10048.69	454508.31	16969.85
51	500	Sum Joints	6966.01	6698.08	0.00	13664.09	859384.88	15078.73	873049	28742.82

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POTENTIAL APPLICATION OF MEMBRANE BIOREACTOR (MBR) TECHNOLOGY FOR TREATMENT OF OILY AND PETROCHEMICAL WASTEWATER IN VIET NAM - AN OVERVIEW

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Summary

Oily and petrochemical wastewaters generated from various activities such as crude oil production, oil refinery, petrochemical industry, metal processing, car washing, etc., are one of the sources of high environmental pollution. These wastewaters were not effectively treated by the conventional activated sludge process due to their toxic and refractory characteristics. In recent years, membrane bioreactor (MBR) technology has been widely applied in various industrial wastewater treatments around the world. Therefore, it would be interesting to employ this technology for treating oily and petrochemical wastewaters in Viet Nam. This paper evaluates the feasibility of using the MBR technology to treat oily and petrochemical wastewaters. The discussions are mainly focused on the operational characteristics, fouling characteristics, fouling control strategies, and costs of the MBR technology in the treatment of these types of wastewaters. It is hoped that this paper could provide useful information for researchers and engineers to develop this novel technology to treat oily and petrochemical wastewaters wastewaters in Viet Nam.

1. Introduction

Oily and petrochemical wastewater (OPW) is complex in composition. It contains high concentrations of biologically inhibitory substances such as petroleum, amines, phenols, polycyclic aromatic hydrocarbons, benzene and its derivative, among others [1 - 3]. This wastewater must be treated before discharging into the environment, otherwise its high mineral and organic content may severely pollute coastal waters, estuaries, rivers, the seashore and soil [4, 5].

Conventional oily wastewater treatment methods, including gravity separation and skimming, air flotation, coagulation, de-emulsification and flocculation and absorption all have intrinsic disadvantages such as low efficiency, high operation cost, corrosion and recontamination problems [6, 7]. More importantly, most of these conventional methods cannot efficiently remove the micron or submicron sized oil droplets. Conventional activated sludge (CAS) process is commonly used to decompose organic substances in wastewater because of its low cost and reasonable efficiency. The OPW is also currently treated by CAS with pre-treatment of oil/ water separation [8]. However, it should be noted that the OPW is low in N and P compounds, the CAS process cannot operate efficiently, as bulking and foaming tend to occur [9]. Furthermore, the high salt concentration of OPW affects the metabolism of the micro-organisms in activated sludge, attenuating endogenous respiration [10]. Similarly, in Viet Nam, OPW was usually treated by using the conventional technologies, such as: coagulation, flocculation, sedimentation, flotation, and biological methods (anaerobic and aerobic). Overall, the treatment efficiency was still low [11 - 13]. Physical treatment of oily wastewater, by such methods as a gravity separator, dissolved air flotation, etc., was not effective in removing the pollutants completely, instead they just transferred them to a more concentrated phase [5]. Moreover, the physical treatment cannot remove the soluble fraction of the wastewater which may contain toxic components such as polyaromatic hydrocarbons [3]. Biological treatment of gas station wastewater is feasible as it contains a portion of easily biodegradable components and, when mixed with domestic wastewater, it receives the essential nutrients such as nitrogen and phosphorus in the form of ammonia and phosphates, which are favourable for the growth of micro-organisms [6]. However, removal efficiency of conventional biological processes is low due to the inhibitive effects of toxic substances and hydrophobic characteristics of the oil components present in them.

Large space requirements also limit the application of conventional biological treatment [10].

In recent years, the membrane bioreactor (MBR), which couples a microfiltration (MF) or an ultrafiltration (UF) membrane with a bioreactor, has received great attention in wastewater treatment [14, 15]. The MBR offers several advantages over the CAS processes. These include excellent quality of treated water, which can be reused for industrial processes or for many secondary household purposes, small footprint size of the treatment plant, and reduced sludge production and better process reliability [1]. So far, MBR has been used for industrial wastewaters such as food processing, pulp and paper, textile, tannery, landfill leachate, and pharmaceutical wastewaters. Also, the European Commission has decided to promote the development of the MBR technology whilst funding four projects entirely dedicated to research, development, capacity building and technological transfer in regards to this promising wastewater treatment process. The four projects, namely AMEDEUS, EUROMBRA, MBR-TRAIN and PURATREAT, are supported by three different financial instruments set up by the European Commission within the sixth Framework Program and were implemented in parallel from October 2005 up to December 2009. By the end of 2009 the total number of MBR systems applied



Fig. 1. MBR process configurations: (a) sidestream, (b) immersed [20]



Fig.2. MBR membrane configurations: (a) multi-tube, (b) hollow fibre (c) flat sheet [21] (with permission from Elsevier publisher, License No: 3058350479403)

to wastewater treatment was about 4,400 around the world [15].

However, there are limited investigations on the treatment and reuse of OPW using MBR technology [16, 17]. The MBR technology is also quite new in Viet Nam. So, it would be interesting to review the available studies of MBRs treating the OPW around the world which could be applied for OPW treatment in Viet Nam in the future.

This study, therefore, was aimed to provide an overview of the MBR technology used to treat the OPW. The present work provides information on the following aspects: fundamentals of MBR technology; factors affecting the MBR treatment of OPW. The potential application, operational conditions and costs of MBRs are also discussed. It is hoped that the information presented in this paper will be helpful for researchers and engineers in developing novel and efficient methods for OPW treatment in Viet Nam.

2. MBR technology and applications of MBR for OPW treatment

2.1. Characteristics of the MBR systems

The two main MBR configurations are shown in Fig.1. Fig.1a shows an MBR in which membranes are installed

> outside the aerobic tank. In this configuration the liquid-solids mixture is pumped around a recirculation loop which contains a membrane unit. The permeate is discharged and the retentate is returned to the aerobic tank. The second and third configurations of MBR have membranes which are either submerged in the aerobic tank or in the membrane tank (Fig.1b). In the submerged configurations, the air was supplied for biological processes and membrane scouring [18]. The submerged MBR is the configuration that is most often applied in wastewater treatment [15, 19].

> Microfiltration (MF) and Ultrafiltration (UF) membranes are frequently employed in MBR applications for industrial wastewater treatments. The membrane configurations used are mainly tubular, hollow fibre and flat sheet (Fig.2). The membrane materials can be classified into three major categories: polymeric, metallic, and inorganic (ceramic). Ceramic membranes can be backwashed, effectively providing high resistance to corrosion and fouling control

[22]. However, they are more expensive than polymeric membranes, such as polyvinylidene fluoride (PVDF), polyethersulfone (PES), polyethylene (PE), and polysulfone (PSf) membranes, which seem to be most widely used in present applications. The pore size of membranes used ranged from 0.01 - 0.45µm [23]. There are essentially two modes of operation of an MBR regarding operating flux: sustainable flux and intermittent operation. Modern practice appears to favour the intermittent operation at sustainable flux that limits rapid and severe membrane fouling [24]. The sustainable fluxes ranged from 25 - 140 and from 3.7 - 85 LMH for external and submerged configurations, respectively.

2.2. Characteristics of oily and petrochemical wastewater

Although OPW has a complex composition, it's characteristics can be presented by basic parameters, such as COD, BOD, SS, NH_4^+ -N, TN, TP, heavy metals, pH, color and turbidity parameters. The typical characteristics of OPW can be summarised as shown in Table 1.

As can be seen in Table 1, despite the substantial variation in results, these data provide a useful guideline for MBR system design. The OPW was high strength wastewater which can contain mixtures of hydrocarbons and oils. OPWs represent one of the most concerning sources of pollution due to their toxic and refractory characteristics. These compounds are poorly biodegradable. The currently available conventional biological wastewater treatment techniques are mostly incapable of complete elimination of the refractory hydrocarbons [31]. Therefore, introducing and developing advanced and high-efficiency wastewater treatment and reuse technologies will have profound significance in sustaining the development of oil refineries. Nevertheless,

tightening effluent regulations and increasing the need for reuse of treated water have generated interest in the treatment of OPW using MBR technology.

2.3. Application of MBR in oily and petrochemical wastewater treatments

Biological treatment technology for treating wastewater containing hydrocarbon is a favourable method and interest has focused on the application of suspended growth biological systems such as the activated sludge process, but high operating expense, weak tolerance to shock loading, and fewer settle-ability problems at high loading rates are still limiting the development of the wastewater process [20].

It should be noted that MBR is a modification of the CAS process, where the activated sludge is concentrated in a bioreactor which is connected to a membrane filtration unit. Due to the high removal efficiency of oily pollutants and the complete retention of suspended solids by the membrane unit, the MBR system shows good potential for application in industry for process wastewater recycling purposes [31].

In this part, some important examples of the MBR technology applied to oily and petrochemical wastewaters are presented. The feasibility of an MBR process to treat petrochemical-contaminated wastewater by using synthetic wastewater containing either fuel oil or lubricant oil and a surfactant was studied [31]. The MBR used in this study was composed of an activated sludge reactor connected to an external tubular cross-flow ultrafiltration unit, as shown in Fig.3.

In the study, a removal efficiency of 99.9% for fuel oil as well as lubricant oil could be achieved at the conditions

Baramotors	Type of oily and petrochemical wastewaters [from different sources]										
Farameters	[1]	[6]	[25]	[26]	[27]	[28]	[29]	[30]			
рН	-	6.5 - 6.8	2.5 - 2.7	7.80 - 8.79	-	_	-	11.5			
COD (mg/L)	72.1 - 296.1	500 - 1,000	55,000 - 60,000	250 - 613	4,345 - 6,864	124	280 - 215	22,250			
BOD (mg/L)	90 - 188	-	30,000 - 32,000	-	919 - 1,360	52	112 - 119	-			
SS (mg/L)	245 - 950	90 - 300	20 - 300	108 - 159	253 - 889	60	-	613			
NH₄⁺-N (mg/L)	12.05 - 19.79	-	-	56 - 125	-	-	13.5 - 19	-			
TP (mg/L)	0.82 - 2.96	-	102 - 227	< 0.5	-	-	5.0	-			
O & G (mg/L)	20 - 87	400 -1,000	360	35 - 55	_	78	17	641			

Table 1. Characteristics of oily and petrochemical wastewaters [1, 6, 25, 26, 27, 28, 29, 30]

of an HRT of 13.3hr, influent with 500 - 1,000mg/L hydrocarbons. The permeate quality was so high that the effluent can be reused in the industrial process. The results clearly showed that the MBR process enhanced permeate quality due to biodegradation of pollutants.

Wastewater from gas stations is characterised by a high concentration of oil-water emulsion which cannot be effectively removed by a conventional gravity separator. An experimental investigation on the treatability of oily wastewater from gas stations using MBR system was studied [32]. The experimental schematic diagram is presented in Fig.4. The results obtained from this study revealed that MBR systems could achieve good removal efficiency with stability against shock loading. Optimum operating conditions were found to be at a hydraulic retention time of 4hr and an oil loading rate of 1.8kg oil/m³.day.

Another important study was that of a UF process followed by an MBR system facility used for treatment of OPW from an automobile engine manufacturing plant [27]. After the upgrading, 90% COD and complete oil, grease and phenolics removals were achieved. This contrasts with the widely fluctuating results in the past. Although most of the reported studies have been conducted on the aerobic MBR and excellent COD removal has been obtained, utilisation of anaerobic MBR in oily and petrochemical wastewater treatment has some inherent benefits. The use of anaerobic MBR for OPW has

Industrial process Waste water feed Industrial process Off gas filter Off gas filter Fresh water Recycling water Filtration unit Bioreactor Air

Fig.3. Schematic of the MBR system used for OPW [31] (with permission from Elsevier publisher, License No: 3058350739834)

also been studied [33]. In this study, an OLR of up to 25kg/ m³.day was observed with an effluent COD normally lower than 500mg/l, corresponding to over 97% COD removal. The OLR was much higher (0.5 - 3kg/m³.day) than that obtained in aerobic ones.

A hybrid of anaerobic and aerobic processes with membrane filtration was conducted to investigate the treatment process of OPW [1]. A schematic diagram of the process flow and pilot plant setup is presented in Fig.5. The results showed that the removal rates for COD and BOD were stable and averaged 92%. The average removal rates for NH₄⁺-N, oil and turbidity were shown to be 93.7%, 75.3% and 94.6%, respectively. The removal rates for TP, TSS, SS and phenol were shown to be greater than 98.5%, 97.9%, 93.8% and 99.9%, respectively. This demonstrated that MBR technology had a superior treatment effect on the above contaminants.

3. Design and operational conditions for MBR systems

3.1. Hydraulic and sludge retention times

Overall, OPW contains a high organic strength resulting in high COD loads. Therefore long hydraulic retention times (HRT) are needed to achieve high biological performance of the MBR system. Typical anaerobic and aerobic HRTs for MBRs used for OPW treatment were in the range of 2 - 10 days and 0.5 - 3 days, respectively [1].

Sludge retention time (SRT) is another important



Fig.4. Experimental setup for the MBR [32] (with permission from NRC Research Press, License No: 3058351422976)



Fig.5. Schematic diagram of the A/O MBR for wastewater treatment [1] (with permission from Taylor & Francis, License No: 3058340986675)

operational parameter. MBR was normally operated with long SRTs and low F/M ratio for reduction of sludge production. However, an increase in SRT would induce an increase in MLSS in the reactor which could have an effect on membrane fouling and could reduce the microbial activity [34]. The proper SRT for MBR systems should be controlled at 20 - 50 days, but highly depends on HRT and the feed characteristics. Typical MLSS values are in the range of 12,000 - 15,000mg/L in submerged MBR [17].

3.2. Operational pH and temperature

Most MBR systems are operated at near neutral pH. However the pH of the OPW is varied largely as shown in Table 1. Therefore, neutralisation and equalisation at a desired pH would be required. The bioaugmentation of an alkaline-tolerating culture in a CAS system that suffered from shocks up to pH 12 is possible [35]. So, similar attempts could be made in MBRs because they are all activated sludge processes.

Most aerobic MBRs are operated at ambient temperatures around 20 - 30°C, whereas anaerobic ones are usually operated at elevated temperatures of 30 - 40°C. An increase in temperature could affect the organic removal efficiency. However, MBRs operated at thermophilic temperatures always show a deterioration of membrane flux although a high flux is anticipated because the flux is inversely proportional to the fluid viscosity [18, 36]. Attention should be paid to improve the membrane flux under thermophilic conditions.

3.3. Membrane fouling control

Membrane fouling represents one of the most challenging issues constraining the more extensive applications of MBRs. Briefly, membrane fouling could be caused by pore clogging by colloidal particles, adsorption of soluble compounds and biofouling, deposition of solids as a cake layer, and the spatial and temporal changes of the foulant composition during a longterm operation [37]. All the parameters involved in the design and operation of MBR processes affect membrane fouling. These factors can be classified into four categories: feed characteristics, biomass characteristics, membrane characteristics, and operational conditions [38]. Optimisation of reactor and module design was also found beneficial to membrane fouling control. With respect to aeration, bubbling requirements for MBRs are typically split into fine bubbles for aeration and larger coarse bubbles for fouling control [39].

3.4. Costs for MBR systems

The overall costs of MBR systems are represented by the sum of the capital, operation, and maintenance costs. The capital costs mainly include costs of membranes, tanks and plant equipment. The operation costs are mainly costs of energy demand, sludge treatment and disposal, and chemical usage for membrane cleaning. The maintenance costs mainly refer to the cost of membrane replacement.

It should be noted that costs of energy demand, sludge treatment, and disposal for a large-scale hollow fibre



Fig.6. Microfiltration membrane replacement costs [43] (with permission from Elsevier publisher, License No: 3058351142243)

submerged MBR accounted for 79.6%, 17.9% and 2.5% of total operation costs, respectively [40]. Energy consumption rates between 0.2 and 2.4kWh/m³ were reported for the submerged operation of municipal and industrial wastewater treatments, and the aeration cost accounted for more than 80% of total energy consumption [17]. The aeration rate and membrane flux would significantly affect operational costs [21]. Therefore, the balance of flux and aeration rate represents a fundamental aspect of MBR design and operation. Membranes themselves represent a significant cost for the full-scale application of MBR systems. Membrane investment costs accounted for 25 - 50% of total capital costs, whereas the membrane replacement costs was about 25 - 33% of total operation and maintenance costs [18].

In general, the cost for MBR technology is higher than conventional activated sludge processes such as CAS and SBR due to the introduction of membranes. However, the membrane life could be up to 11 years [41]. So, if the membrane service time is extended, the costs of membrane replacement would be reduced significantly. In addition, the production cost of membranes decreases significantly year after year [42]. It appeared to have decreased exponentially over the past 10 - 15 years, with whole life costs decreasing from 400USD/m² in 1992 to below 50USD/m² in 2005 as shown in Fig.6 [43]. The rapidly decreasing membrane cost is an important driving force for the widespread application of MBRs.

4. Conclusions and Remarks

Based on the information reviewed from various literature sources it was concluded that MBR technology appears to be a prospective technology for OPW treatment. The treatment can be performed using the

Abbreviations

BOD: Biological Oxygen Demand
CAS: Conventional Activated Sludge
COD: Chemical Oxygen Demand
DO: Dissolved Oxygen
F/M: Food to Microorganisms ratio
HRT: Hydraulic Retention Time
MBR: Membrane Bioreactor
MF: Microfiltration MLSS: Mixed Liquor Suspended Solids
N: Nitrogen
OLR: Organic Loading Rate
OPW: Oily and Petrochemical Wastewater
P: Phosphorus
SRT: Sludge Retention Time
TMP: Transmembrane Pressure
UF: Ultrafiltration

submerged MBR or side-stream MBR. The OPW treated by using MBR can produce product quality that consistently meets the requirement for discharge.

However, MBR systems still face several challenges when applied to OPW treatment. It is worth noticing that application of the membrane fouling control strategies represents the involvement of the operational cost, energy, and manufacturing issues in the MBR systems. Therefore, some key remaining issues need to be addressed in the application of the MBR technology to the treatment of OPW such as the effect of high concentration of oil and grease in the feed on the biological process and membrane fouling; also the effect of pre-treatment on oil before the wastewater enters the MBR system. Besides, there is a scarcity of economic evaluation applied in the field based on full-scale applications. These limitations should be overcome to push the development of MBR technology in OPW treatment.

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PETROVIETNAM NEWS

PVEP discovers gas in Block M2, offshore Myanmar

On 8 June 2013, SYT-1X, the first exploration well in Block M2, offshore Myanmar, was successfully tested with the first gas discovery. With the discovery of gas from Block M2, Petrovietnam's strategy is paying off in reaching out to overseas markets, especially in Myanmar with all its potential. Witnessing this event, H.E. Mr. Nguyen Thanh Dung, Vietnamese Ambassador to Myanmar, said, "The gas discovery in PVEP's first exploration well in Myanmar is an outstanding event which contributes to strengthening the special relationship and cooperation between the governments of Viet Nam and Myanmar".

The Production Sharing Contract (PSC) for Block M2 was signed on 2 October 2008 between Myanmar Oil and Gas Enterprise (MOGE) and a group of contractors including PVEP, Vietsovpetro and a local company, the Eden Group Company Limited. The PSC came into effect on 1 January 2009. In the first Exploration Phase, PVEP took over Vietsovpetro's share and became the biggest partner with 85% of participating interest. In May 2013, PVEP transferred part of its participating interest to Maurel & Prom, a French company.



Vietnamese Ambassador to Myanmar Nguyen Thanh Dung, and PVEP's leaders along with technicians working on the Trident 16 platform at Block M2, offshore Myanmar. Photo: PVEP

From the beginning, PVEP has conducted an active exploration program including 2D seismic acquisition in 2010, 3D seismic acquisition in 2012, and then a rapid preparation and the start of a drilling campaign for two exploration wells in 2013. The SYT-1X gas discovery brings hope for further discoveries in the subsequent extended exploration wells so that the project can enter a Development Phase. Manh Ha

Workshop and coaching on production, safety for Te Giac Trang and Ca Ngu Vang fields



Te Giac Trang Wellhead Platform H4. Photo: PVEP

Recently, in order to optimise the production of Te Giac Trang and Ca Ngu Vang fields, Hoang Long - Hoan Vu JOC's organised a workshop on "Minimising operational downtime at Te Giac Trang and Ca Ngu Vang fields". At the workshop, the direct, indirect and potential causes of downtime were presented in parallel with their management and technical resolution. The participants contributed and shared many important ideas focusing on minimising operational downtime and optimising production in order to secure the oil and gas production output plan. Giving the closing speech at the event, Dr. Cu Xuan Bao - General Manager of Hoang Long - Hoan Vu JOC's stated that he highly appreciated such practical production meetings and emphasised the need to realise the ideas developed at the workshop.

In addition, Hoang Long - Hoan Vu JOC's also combined a coaching section on Safety Audits so as to reinforce the knowledge and skills of staff. The training was also an open forum with ideas and contributions from trainees, from key safety audit and inspection personnel to office staff. Hoang Long - Hoan Vu JOC's always commit to strict compliance with health, safety and environmental policies.

In 2012, Ca Ngu Vang field's production achieved 116% of target, Te Giac Trang field's production was 122%, operational up-time for the total production system was 99.9%; cost savings versus budget realised 12% (USD 45.7 million), and added revenue USD 330 million.

Khanh Linh

JCCP/JX-NRI to develop and transfer LP software technology for Dung Quat Refinery



Mr. Nguyen Viet Thang, Vice President of BSR, and Mr. Morihiro Yoshida, JCCP Managing Director, signed the Memorandum of Agreement. Photo: VPI

On 20 June 2013, a signing ceremony was held at the Vietnam Petroleum Institute's headquarters in Hanoi for the Memorandum of Agreement (MOA) between Binh Son Refining and Petrochemical Co. Ltd. (BSR) and Japan Co-operation Centre, Petroleum (JCCP) on "LP software technology transfer and energy saving project". Also attending and witnessing the signing ceremony were Mr. Michio Daito, Counsellor of the Japanese Embassy in Viet Nam, and representatives from JX-Nippon Research Institute (JX-NRI), the Vietnam Petroleum Institute (VPI), the Petroleum Processing Division of Petrovietnam, and the Research and Development Centre for Petroleum Processing of the Vietnam Petroleum Institute (VPI-PVPro).

According to the MOA, JCCP/JX-NRI will develop and transfer the LP model to support the assessment of work plans, development of long-term and medium-term plans and planning of refinery improvement for new refineries in general and for Dung Quat Refinery in particular. This model can also be used to determine the minimal energy consumption level, which helps the refinery use energy in a more economical and efficient manner.

According to Dr. Phan Ngoc Trung, General Director of the Vietnam Petroleum Institute, the project will contribute to strengthening the close relations between Petrovietnam and JCCP as well as between JX-NRI and BSR/VPI. The project was launched when Dung Quat Refinery has been operating stably for 3 years with a processing capacity of 6.5 million tons of crude oil every year, supplying over 30% of the domestic fuel demand. It is now the strategic time to conduct research and apply optimal solutions to improve the refinery's efficiency and save energy. Vinh Loc

PVEP and Maurel & Prom sign farm-out agreement for Block M2

On 31 May 2013, Petrovietnam Exploration Production Corporation (PVEP) and Maurel & Prom Exploration and Production Company signed the Farmout Agreement relating to Block M2, offshore Myanmar. According to the agreement, PVEP will transfer part of its participating interests in Block M2 to Maurel & Prom.

The petroleum contract for Block M2 in Myanmar was signed on 2 October 2008 in Yangon between Myanmar national oil company MOGE (Myanmar Oil and Gas Enterprise) and a group of contractors, PVEP as the operator, Vietsovpetro and Eden Group. Located offshore of the Mottama basin, Block M2's area is approximately 10,000km² and is around 200km from the former capital of Yangon. The water depth in Block M2 is below 200m. It is close to Block A7 to the north, Block M3 to the east where gas has been discovered and is ready to be brought on stream and Block M5 to the south where the 5TCF Yadana gas field was found. PVEP took over Vietsovpetro's share during the first exploration phase.



Farm-out agreement signing ceremony. Photo: PVEP

PVEP decided to transfer part of its interest to Maurel & Prom with an aim to reduce risks in the exploration operations as well as to deploy the experience and technology of their French partner in developing the block. This is a step in PVEP's efforts to restructure its investment portfolios in order to ensure sustainable future development. Manh Hoa

Dung Quat Refinery imports 300th batch of crude oil



Shipping crude oil to Dung Quat Refinery. Photo: BSR

n 11 June 2013, Binh Son Refining and Petrochemical Company (BSR) received the 300th batch of crude oil for Dung Quat Refinery. This batch, which has the total volume of 80,000 tons, came from Bach Ho field.

Since the refinery was put into operation in 2009, it has imported a total of 23.95 million tons of crude oil, of which 20.575 million tons were sourced from Bach Ho field and other oil fields in Viet

Nam, and the remaining were imported from other countries.

BSR plans to increase the amount of crude oil imported from abroad to gradually replace that extracted from Bach Ho field. In the first five months of 2013, Dung Quat refinery has processed 3.1 million tons of crude oil to produce 2.7 million tons of products and generated over VND 60 trillion (USD 2.88 billion) in revenue. Manh Hung

PTSC to build topsides for a central process platform of India

PTSC has recently won the international bid to build and load out the topsides for a central process platform for Afcons and ONGC (Oil and Natural Gas Corporation) at Heera Redevelopment Project (HRD) in South Heera, offshore Mumbai, India. The fabrication works under the contract will be executed by PTSC Mechanical & Construction (PTSC M&C), a member of PTSC.

All the fabrication and assembly works will be carried out at PTSC downstream port in Vung Tau city. With its established capacity and experience, PTSC is confident about the success of this project, stressing that it will be implemented on schedule with safety and quality. The project will commence in June 2013 and the load-out is planned to take place in November 2014.

Kim Anh

PVFCCo receives Certificate of Operational Excellence from Haldor Topsoe

A delegation of Petrovietnam Fertilizer and Chemicals Corporation (PVFCCo) led by Mr. Cao Hoai Duong, President & CEO, visited Denmark in May 2013 and had a working session with Haldor Topsoe A/S, licenser of the ammonia production technology used at Phu My Fertilizer Plant cum provider of technological services and catalyst for PVFCCo. The two companies shared information about their business status and discussed co-operation programmes in recent years and for the future.

Mr. Bjerne S. Clausen, CEO of Haldor Topsoe, on its 10th congratulated PVFCCo anniversary of development and awarded the Certificate of Operational Excellence to PVFCCo for its outstanding records of safe and stable operation of Phu My Fertilizer Plant, which has achieved and exceeded the design capacity for many years and recently made the 2nd world record of 188 day continuous operation.

Over 10 years of operation, PVFCCo has defined its



CEO of Haldor Topsoe awarded the Certificate of Operational Excellence to PVFCCo. Photo: DPM

position as one of the biggest fertilizer producers and businesses in Viet Nam, serving as a key tool of the State in fertilizer market stabilisation and national food security assurance. The success of PVFCCo's technical staff in the effective management and safe and stable operation of Phu My Fertilizer Plant has marked a significant step in the development of the petrochemical industry of Viet Nam.

PTSC Marine supplies service vessels to Lam Son JOC

Operating Company (Lam Son JOC) signed a contract for the provision of service vessels. Accordingly, PTSC Marine will supply one 10,880 BHP - DP2 service vessel and one 8,080 BHP - DP2 service vessel, with a total value of nearly USD 15 million. Both vessels will serve Lam Son JOC's drilling activities at Thang Long -Dong Do field for a period of 1 year (starting from late July 2013).

Being a leading provider of service vessels in Viet Nam and in the region, PTSC/PTSC Marine in the past years has provided timely, safe and efficient services to facilitate Lam Son JOC's production activities. The signing of the service versel supply agreement between PTSC Marine and Lam Son JOC once again confirms



PTSC Marine and Lam Son JOC signed a contract for the provision of services vessels. Photo: PTSC

the traditional relationship and the good co-operation between the two companies. Nguyen Oanh

PVC-MS starts fabrication of BK17 topside



PVC-MS strives to complete the project on 30 August 2013. Photo: PVC

On 3 June 2013, Petroleum Equipment Assembly & Metal Structure Joint Stock Company (PVC-MS) started BK17 topside fabrication project. This is a project for which Vietsovpetro is the investor.

BK17 topside is a lightweight exploration platform which will operate in Bach Ho field. PVC-MS will fabricate and install the topside and the technological systems, and connect the topside with bearing beams. The total weight of the topside and its technological pipe systems is about 360 tons.

As this project is urgently required, PVC-MS has mobilised 150 employees to work 2 shifts/day and strengthened measures for project management and quality and labour safety monitoring. It is expected that on 30 August 2013, PVC-MS will complete BK17 topside and hand over the structure to Vietsovpetro. Minh Phuong PVI and Formosa sign insurance contract



Insurance contract signning ceremony

On 31 May 2013, PVI Insurance Corporation (PVI Insurance) and Formosa (Taiwan) signed an insurance contract for the construction and installation of "Formosa Son Duong Steel and Port Complex" with a total insured value of USD 5 billion for the construction and installation items.

Thu Ha

PV Power Coal provides 3,000 tons of coal for Dung Quat Bioethanol plant

PV Power Coal has recently supplied 3,000 tons of coal to cater for the test runs and acceptance of Dung Quat Bio-ethanol Plant. In the future, PV Power Coal will continue to make arrangements for long-term supply of coal for the boiler and generator of the Bio-ethanol Plant during its commercial operation. Nguyen Hanh

OIL & GAS MARKET



OIL & GAS GLOBAL MARKET

 Table 1. Worldwide supply and demand (million b/d)

2nd Quarter

89.3

44.7

23.6

13.3

7.8

4.6

0.7

9.7

11.7

6.6

7.8

3.5

90.2

20.1

16.3

3.2

0.5

29.7

13.6

0.1

4.2

3.5

4.3

1.5

2.4

2.2

2.0

36.4

30.0

6.4

54.0

44.6

2013

3rd Quarter

91.1

45.9

24.0

13.9

8.0

45.1

4.8

0.8

9.7

11.3

6.8

8.2

3.5

90.7

20.1

16.5

3.1

0.5

29.5

13.4

0.1

4.2

3.4

4.4

1.5

2.4

2.2

2.4

36.6

30.0

6.6

54.1

4th Quarter

91.6

46.3

24.1

13.8

8.4

4.9

0.7

10.0

11.8

6.7

7.7

3.5

91.3

20.7

16.8

3.3

0.5

29.8

13.6

0.1

4.2

3.4

4.5

1.5

2.5

2.2

2.1

36.6

30.0

6.6

54.7

45.3

Year

90.5

45.7

23.8

13.6

8.3

44.8

4.7

0.7

9.8

11.6

6.6

7.8

3.5

91.0

20.3

16.5

3.3

0.5

29.7

13.6

0.1

4.2

3.5

4.4

1.5

2.4

2.2

2.0

36.8

30.3

6.5

54.2

2013 is a year of		Та	ble 1. Wor	ldwide supply
continuing relocation				
of the growth centers	No	Demand/ Supply	2012	1 st Quarter
for supply and demand	Α	Demand	89.8	90.0
as global demand for	1	OECD	46.1	46.0
oil in particular remains		North America	23.8	23.6
strongly linked with OFCD		Europe	13.8	13.4
and specially US economic		Pacific	8.5	9.0
recovery performances.	2	Non-OECD	43.7	44.0
Additionally, the		FSU	4.6	4.6
sovereign debt crisis		Europe	0.7	0.7
in Europe continues to		China	9.5	9.9
worsen, plus the risk of		Other Asia	11.4	11.6
increased tensions in		Latin America	6.5	6.4
different regions of the		Middle East	7.6	7.3
globe is unanticipated.		Africa	3.4	3.5
For all these reasons,	В	Supply	90.9	91.1
forecasting the likely	1	OECD	19.7	20.3
worldwide oil and gas		North America	15.7	16.4
supply and demand		Europe	3.4	3.4
figures is a difficult		Pacific	0.6	0.5
task. Nevertheless, the	2	Non-OECD	29.6	29.7
International Energy		FSU	13.7	13.7
Agency (IEA), at the end		Europe	0.1	0.1
of 2012, presented a		China	4.2	4.2
forecast concerning the		Other Asia	3.6	3.5
supply - demand balance		Latin America	4.2	4.2
for 2013, in which we can		Middle East	1.5	1.5
see the situation is quasi-		Africa	2.3	2.4
stable (Table 1). Generally,	3	Processing gains	2.1	2.2
the supply would be	4	Global biofuels	1.9	1.6
higher than the demand	5	OPEC	37.6	37.3
with a difference at least		Crude oil	31.4	31.0
of 500,000b/d, but the		NGL	6.2	6.3
fluctuation may occur	6	Total non-OPEC	53.3	53.8
mainly in the 3^{m} and 4^{m}	Sourc	e : Oil and Gas Journal,	7 January	2013
quarters.		- ,		

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On the other hand, in its Short-Term Energy Outlook (STEO), issued on 8 January 2013, the US Energy Information Administration (EIA) forecasts a fairly loose Oil market during the next 2 years as higher global consumption will be more than offset by increasing global supply. Worldwide oil supply is expected to increase by 1 million b/d in 2013 and by 1.7 million b/d in 2014 with most of the growth coming from producers outside the OPEC. EIA also forecasts that non-OPEC production will rise by 1.4 million b/d in 2013 and by 1.3 million b/d in 2014. With continued increased production from US tight oil formations and Canadian oil sands, EIA sees North America accounting for two thirds of the projected growth in non-OPEC supply. A decrease of 600,000b/d in OPEC crude supply is expected in 2013, with the production reduction from Saudi Arabia. However, OPEC crude production will remain at least 30 million b/d over the next 2 years with increased production from Iraq, Nigeria and Angola. The growth of world liquid fuels consumption will remain flat in 2013 by an estimated 900,000b/d. Due to a moderate recovery of global economic growth, worldwide liquid fuels consumption will pick up again in 2014 to an annual average of 1.3 million b/d. Most of the increase in the world's oil consumption will come from countries outside the OECD over the forecast period. EIA projects OECD

consumption to further decline by 300,000b/d in 2013, as modest consumption increases in North America are more than offset by decreasing consumption in Europe. Higher economic growth and flattened European consumption in 2014 will narrow the OECD consumption decline to 100,000b/d.

World oil prices

According to <u>www.bloomberg.com/news 20130507</u>, the US Energy Information Administration reduced its crude-oil price forecast for 2013 issued in the first quarter of current year because of falling futures and increasing production outside the OPEC.

West Texas Intermediate oil will average USD 93.17 a barrel this year, down 75 cents, or 0.8%, from the April projection of USD 93.92. The US benchmark grade will average USD 92.25 in 2014, unchanged from the previous month's estimate. WTI crude for June delivery fell 52 cents or 0.5%, to USD 95.64 a barrel at 12:19pm on the New York Mercantile Exchange. The US grade dropped 3.9% to USD 93.46 in March. Brent oil for June settlement declined 38 cents, or 0.4%, to USD 105.08 on the London-based ICE Futures Europe Exchange. North Sea crude tumbled 7% to USD 102.8 in May. The EIA forecasts that Brent, the

	Dec	2013										
Data	2012	1 Jan.	15 Jan.	30 Jan.	15 Feb.	28 Feb.	15 Mar.	30 Mar.	15 Apr.	30 Apr.	15 May	5 June
OPEC Reference basket	106.5	108.3	105.2	108.6	113.5	106.7	106.2	106.0	96.3	100.9	99.7	
WTI USA	96.3	98.3	94.5	97.5	96.1	91.5	93.5	97.0	88.0	84.0	100.0	93.80
Brent North Sea	109.3	111.6	108.5	112.0	117.0	110.0	109.5	109.3	99.27	104.0	102.8	103.24
Arabia light Saudia Arabia	108.3	109.4	106.3	109.8	114.7	107.8	107.3	107.1	97.3	101.9	100.7	
Basrah light	105.0	106.2	103.1	106.4	111.1	104.5	104.0	103.8	94.3	98.8	97.7	
Bonny light	111.2	113.8	110.7	114.2	119.3	112.2	111.7	111.5	101.3	106.1	104.9	
Es Sider Libya	109.3	111.6	108.5	112.0	117.0	110.0	109.5	109.3	99.27	104.0	102.8	
Girassol Angola	108.9	110.0	107.9	111.4	116.4	109.5	108.9	108.7	98.8	103.5	102.3	
Iran heavy	106.6	107.4	104.4	107.7	112.5	105.8	105.8	105.1	95.5	100.0	98.9	
Kuwait export	106.2	107.0	104.0	107.5	112.2	105.5	105.0	104.8	95.2	99.7	98.6	
Marine Qatar	106.3	111.1	103.4	106.7	111.5	104.8	104.3	104.2	94.6	99.1	97.9	
Merey Venezuela	91.68	99.1	94.4	97.4	101.8	95.7	95.3	95.1	86.3	90.5	89.4	
Murban UEA	108.9	109.1	106.1	109.5	114.4	107.6	107.1	106.9	97.1	101.7	100.5	
Oriente Ecuador	98.68	99.5	96.8	99.9	104.3	98.1	97.6	97.5	88.5	92.7	91.7	
Algeria Blend 44°	109.9	112.1	109.0	112.5	117.6	110.5	110.0	109.8	99.76	104.5	103.3	
Minas 34º Indonesia	109.0	113.3	110.1	113.7	118.7	111.6	111.1	110.9	100.7	105.5	104.3	
Fateh 32° Dubai	106.3	106.7	103.7	107.1	111.8	105.1	104.7	104.5	94.9	99.4	98.3	
Isthmus 33° Mexico	99.03	107.1	104.1	107.5	112.3	105.6	105.1	104.9	95.3	99.8	98.7	
Urals Russia	108.2	110.0	107.0	110.4	115.3	108.4	107.9	107.7	97.9	102.5	101.3	

Table 2. Oil prices from December 2012 to June 2013 (USD/b)

Sources: Oil Prices; Oil and Gas Journal 2013

benchmark grade for more than half the world's crude, will average USD 105.89 a barrel in 2013, down USD 2.07 from last month's prediction. The average cost of domestic and imported grades used by US refiners will be USD 98.12 a barrel this year, down 64 cents from the April projection of USD 98.76 and USD 96.99 next year. Brent will drop to USD 100.75 a barrel next year.

World Oil prices from December 2012 to June 2013 are presented in the Table 2.

In the actual politico- economical and security environments of the world, the uncertainty of the future oil price forecast is inevitable. Factors that will make oil cheaper are:

- Oil technology development rapidly contributing to discovering and extraction of a great amount of conventional and unconventional hydrocarbon in different regions of the globe;

- OPEC and Russia increase their production;

- Slow economic growth in China, India and OECD countries and the moving towards the utilization of gas in electricity production which could lead to lower global oil consumption;

- Lesser oil consumption in USA and in other countries due to new energy policies;

- Lower economic- social activities can translate into lesser demand for oil due to sluggish global economic recovery.

On the contrary, the main factors that would make oil more expensive could be:

- The results of the global economic recovery are more positive than expected;

- OPEC and Russia production is restricted to protect the oil price at a high level;

- Lesser consumer spending on green energy or lower budgets means less government incentive for sponsoring green energy endeavors;

- More natural disasters with high devastation intensity develop;

- Geopolitical tension in the world is not limited. If military action occurs, oil export-imports may drop dramatically or even stop for weeks or months and at this moment the oil price is unimaginable.

However, based on the oil prices trend in the first half

of the current year, most forecasters predict the global oil price will be higher in the short term than at the present day but with a moderate rate of increase.

The prices of gasoline and oil products in general also remain high, even when the crude oil price is going down. There are numerous reasons responsible for the divergence between the oil and gasoline prices trends. In the USA market, the price of gasoline at the pump is determined by various complicated factors and a whole range of issues which includes the demand and supply of crude oil along with factors like inflation, local taxes and changes in currency valuations as follows:

- The US has the largest emergency oil supplies in the world. The release of oil from strategic petroleum reserves pushes prices down as the supply of oil is increased;

- Eurozone crisis: The safe haven buying of dollars because of concern over Eurozone instability. An exit of any European country from the Eurozone will have a disastrous effect on the markets and the resulting recession would cause oil prices to dive further;

Inflation: the gasoline price is high because the value of the USD is low;

- The pricing of gasoline can fluctuate independently from that of crude oil;

The overlapping effect of federal and local taxes regimes.

A typical breakdown of the per litre gasoline price would be as follows: Price of crude oil - 68%; refining costs - 10%; state taxes - 10%; distribution and marketing costs - 5%; profit margins - 7%. Though demand and supply is responsible for substantial hikes, distributors are to be blamed on all other occasions. It is right that the moment there is speculation that crude will be trading higher, retailers usually increase their prices in an attempt to keep their margins intact for future purchases. However, when the price of crude decreases, retailers are not inclined to lower rates as fast as they have raised them in order to maximize profits. When crude is in an upward spiral, the retailers have little or no opportunity to earn profits. But when the crude is cheaper, they see a chance to capitalize on the situation and delay lowering the prices at the pump. With no new refinery built since 1976, the US is experiencing considerable fluctuations in gasoline prices partly because its current refining capacity can not meet its increasing energy needs. The same situation is seen in other OECD and developing countries.

LNG markets

Within the big oil and gas importing countries, Korea is now paying the highest price for LNG. But now the situation would seem to be improved. Korean LNG demand could slip by an average of 0.1% a year up to 2027 as renewables play a bigger role in power generation, although there is scepticism about the renewables targets. The Korean Ministry of Trade, Industry and Energy (MOTIE) forecasts LNG demand will increase from last year's 38.29 million tons to 39.77 million tons in 2015 before falling to 33.97 million tons by 2020 with the startup of new base-load power plants running on nuclear and coal from 2016 - 2018. Demand will rise to 37.7 million tons by 2027, still 1.5% lower than last year. Right now, 47% of Korean demand comes from the Middle East, 33% from South East Asia, and the rest from Russia, Australia and Africa. But in the future Korea will import around 10 million tons/year of shale derived LNG from North America. The implication is that any new deals will be in North America. However analysts say the uncertaintyis that it is hard to predict long-term LNG demand as Korea will have to import more gas if it falls short on renewables, which should become clearer over the next two years.

Natural gas and LPG prices

US natural gas struggled in vain earlier this week to hold a floor around USD 4/MMBtu after fundamental and technical factors arrested the week's three-session 36.7 cents loss. The 8.4% plunge followed on the heels of an April 29 rally by the newly minted June prompt-month, which lifted prices by 16.9 cents to USD 4.392/MMBtu. By 2020 US gas export could potentially reach around 8 billion ft³ per day (66MMtons/year) compared to the 77 million tons/year that global LNG leader Qatar ships to the market today. The exploitation and development of trillions of ft³ of US shale gas is helping drive down prices to around USD 3.5/MMBtu now, and creating good

Tabl	e 3. /	Nymex	US	gas	futures	(USD)	/MMBtu
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Contract	22 April	15 April
June	4.29	4.16
July	4.33	4.21
August	4.36	4.24
September	4.34	4.23
October	4.34	4.24
November	4.40	4.30
December	4.55	4.45

Source: WGI, 24 April 2013

conditions for a rebirth of the US petrochemicals industry, part of which had essentially been moribund for up to 25 years. Fertilizers were the first petrochemicals business to recover followed by ethane crackers moth-balled when US plants became uneconomic.

In March, LNG North East Asian prices surged to USD 19/MMBtu as buyers raised bids for cargoes for delivery at the end of February, while prices in South West Europe rose to USD 14.7/MMBtu as demand increased for re-exports from South America and Turkey, according to WGI assessments. The day-ahead price at the UK National Balancing Point (NBP) fell to USD 10.37/MMBtu on milder weather, while February futures inched up to USD 10.5/MMBtu. Netbacks for Mideast sellers were USD 4 higher on Asian than Southwest Europe deliveries, while UK and Belgian netbacks for Mideast sellers lagged Asia by over USD 9.

In Asia, Japan's Kyushu Electric Power has reportedly agreed a deal with Russia's Gazprom for one cargo in the low USD 19 for delivery in late February or early March. A Chinese importer says his firm has met March requirements and is still deciding about April, but will only pay less than USD 19/MMBtu. LNG plants in the Pacific Basin are offering very few flexible cargoes. The market also appears tight in Europe, where reloads to South America are gathering pace. There is so much demand for re-export cargoes that hardly any are available at the moment Buyers are under pressure to increase theirs bids, with sellers in some instances reportedly asking for USD 16/MMBtu. Turkey and Greece are both seeking LNG for delivery at the end of February or in March quoting prices of USD 13.5 - USD 14, but have met with little response from suppliers.

In May, LNG prices in Northeast Asia slumped 45 US cents to USD 14.3/MMBtu as buyers held off on closing deals during Japan's holiday season, forcing sellers to lower offers. This was the 12th consecutive weekly drop from a near-term peak of USD 19.4/MMBtu in February. Prices in Southwest Europe also fell to USD 11.75. NBP dropped to USD 10.02, while June NBP futures fell to USD 11.75/MMBtu. Netbacks for Mideast sellers were around USD 2.35 higher on Asian than on Southwest Europe deliveries, while UK-Belgian netbacks for Mideast sellers lagged Asia by USD 5 (Table 4).

Thailand's state PTT secured cargoes after its tender closed in May with some market players saying the June shipment was about USD 14/MMBtu. Bids for second-half June cargoes were lowered to the high USD13s or low USD14s, while offers were heard in the mid USD14s.

Singapore's first LNG import terminal has started commercial operations with the May 7 arrival of the first commercial cargo on MethaneKari Elin from aggregator BG. Qatar supplied a commissioning cargo in March. Malaysia is also racing to open its Melaka terminal, originally due to launch last year, with a Nigerian commissioning cargo arriving on 30 April. Malaysian state Petronas is understood to be sourcing its next cargoes from Statoil and GDF Suez, with which it has signed shortterm deals.

Japanese utilities are expected to start procuring July cargoes after the holidays, although volumes will be limited as many have covered summer requirements with term supply.

Prices in Southwest Europe are now at their lowest this year following seven straight weeks of decline. In Spain, ample hydropower has caused industrial gas demand to plummet, with grid operator Enagas forecasting reloads will double between April and May. In Northwest Europe, prices for June cargoes are around USD11. Belgium and the UK will share Norwegian Snøhvit's first export since unplanned maintenance in February.

Two recent tenders in South America - from Argentina's YPF and Enarsa, and Mexico's CFE - underscore continued demand in the region, with offloaded record of 56.3 million tons in April. Argentina is looking to secure seven cargoes for 2013 delivery, while Mexico wants 31 cargoes over the next 18 months. Sources say Argentina's credit risk means offers may be higher than anticipated,

Market Exporter	Northeast Southwest Asia Europe		UK	Belgium Zeebrugge		
Qatar	12.32	9.96	7.23	7.31		
Oman	12.49	10.12	7.49	7.44		
AbuDhabi	12.36	10.00	7.31	7.35		
Indonesia	13.34	9.18	6.62	6.46		
Malaysia	13.28	9.25	6.69	6.77		
Australia	13.09	9.14	6.61	6.60		
Russia	13.84	8.71	6.27	6.34		
Trinidad	10.40	10.70	8.00	8.04		
Algeria	11.12	11.45	8.42	8.47		
Egypt	11.56	11.09	8.13	8.21		
Nigeria	11.11	10.64	7.89	7.93		
Eg. Guinea	11.20	10.71	7.92	8.00		

Table 4. Spot LNG exporter netbacks at some key markets worldwide

Source: WGI 8 May 2013

although the Mexican cargoes could end up being offered at a premium to Argentina's because of the longer shipping distance.

Two recent charter deals indicate rates have softened, with newer vessels commanding higher rates. Golar Viking was chartered to Eni for USD 93,000/day for 1 month, while Spain's Gas Natural has taken LNG Libra, built in 1979, for USD 33,000/day for 5 months.

Oil and gas asset market

North Sea Midstream Partners, Boston, has purchased Teesside Gas Processing Plant Ltd (TGPP) from a consortium of Deutsche Bank. TGPP operates a 450 MMScfd gas plant at seal Sands on Teesside, UK, capable of high level of NGL extraction. In this year's first half the plant will start up a second processing train that will add 225 MMScfd of capacity initially dedicated to the RWE operated Breagh project in the Southern Gas Basin.

OAO Lukoil signed an agrement with Hess Corp. to acquire 100% of Hess's Samara - Nafta for a total of USD 2.05 billion. Based on its 90% interest in Samara-Nafta, total after tax proceeds to Hess are expected to be USD 1.8 billion. Samara-Nafta is currently producing 50,000b/d in Russia's Volga - Urals region.

So far this year, Hess has reported or completed the sale of interests in Beryl field in the UK North Sea, the Eagle Ford play in Texas and the Azeri, Chirag and Guneshli fields in Azerbaijan and the associated pipe. Including Samara - Nafta, the total after tax proceeds from these sales will amount to about USD 3.4 billion.

Sanchez Energy Corp, Houston, will buy South Texas Eagle Ford shale properties an acreage from Hess Corp. for 265 million USD cash. The acquisition involves assets with high working interests in 43,000 net acres in Dimmit, Frio, Lasalle and Zavala counties. The properties are producing 4,500b/d, 72% oil, from an estimated 13.4 million boe of proved reserves.

ONGC Videsh Ltd., New Delhi, has completed its acquisition of Hess Corp.'s 2.721% interest in the Azeri, Chirag, and deep water Guneshli fields in the Caspian sea offshore Azerbaijan and 2.36% interest in the Bacu-Tbilisi-Ceyhan Pipeline.

Royal Dutch PLC is willing to invest several hundred million dollars over 6 - 8 years in companies with emerging technologies that can help its operations. Targeted technology areas include gas production and conversion, geophysical imaging, chemical manufacturing and conversion, novel materials, enhanced oil recovery and water treatment.

Rosetta Resources Inc. is entering the Permian basin with plans to buy assets from Comstock Resources for USD768 million, subject to customary closing adjustments. The acquisition covers 53,306 net acres in Reeves and Gaines counties in west Texas. Total current net production is 3,300b/d, of which more than 73% is oil.

Mitsui & Co. Ltd. will acquire Total SA's Italian subsidiary that holds a 25% participating interest in supergiant Tempa Rossa oil field in Southern Italy, the largest proved undeveloped onshore oil field in Western Europe, from which production is projected to start in 2016.

Cairn Energy PLC will take a farmout from an Australian company and become the operator of three exploratory blocks offshore Senegal. The three blocks total 7,490km² from near shore to deep water over the shelf, slope, and basin floor of the Senegalese part of the productive Mauritania-Senegal-Guinea-Bissau basin. The acreage is covered by a 2,050km² of 3D seismic survey and a number of plays types, leads, and prospects have been identified.

Regional oil market update

Malaysia: The Refinery & Petrochemical Integrated Development (RAPID) project proposed by Petronas is on track for a final investment decision (FID) by mid-2013. RAPID is to be located in Pengerang, Johor state, where a refinery will have a capacity of 300,000b/d to supply feedstock for a petrochemical complex as well as produce gasoline and diesel in compliance with European specifications. Rapid aims to meet the growing need for speciality chemicals and demand for petroleum and commodity petrochemical products in the Asia Pacific region by 2016. The project has progressed to the front end engineering and design (FEED) stage, and Petronas is finalising the selection of potential partners and licensors for various project facilities. Additionally, Petronas has signed an agreement with BASF on a 40:60 basis to jointly own, develop, construct and operate production facilities for special chemicals and plants for precursor materials within the RAPID complex.

Petronas and Total have signed a heads of agreement to study the development and production of K5, a high CO_2 gas field offshore Sarawak K5, discovered in 1970, is a sour gas field with up to 70% CO_2 content located 230km from Bintulu in water depth of 80m. Should K5 prove feasible, it will be the first gas field developed in Malaysia with more than 50% CO_2 .

Petronas will use its recently established Exploration and Production Technology Centre while Total will investigate the possibility of developing the field in a technically, commercially and environmentally viable manner. The 15-month study will include the development of CO₂ management technologies in the areas of carbon capture, transportation and sequestration.

Thailand: The Greater Bongkot South Gas and Condensate field in the southwestern sector of the Gulf of Thailand is now producing. Located in Block B16 and B17, Greater Bongkot South has new falicities with a processing capacity of 350mmcf/d of gas and 15,000b/d of condensate. Gas is transported via a spur line to the PTT grid while condensate is exported 70km to Modec's floating, storage and offloading vessel FSO Pathumabaha at Greater Bongkot North.

Philippines: In the fourth Philippines Energy Contracting Round (PECR4) nine oil and gas proposals have been accepted by the Department of Energy out of 16 submitted. The bids involved twelve of fifteen PECR 4 permits. Accepted offers came from Forum Pacific; a consortium of Philodrile and Philex Petroleum; Min Energy; Loyz Oil; a consortium of Mitra Energy, Kufpec and Tap Oil; Helios Mining & Energy; and Dil Moro Energy.

The concessions are located in Cagayan and Central Luzon, offshore Northwest and East Palawan, Mindoro-Cuyo Basin, Cotabato Basin and the Sulu Sea, which received the most attention in this preliminary round. Areas 3, 4 and 5 offshore Northwest Palawan Island are to be proffered in July. These three concessions are thought to be of particular interest as they are near Malampaya and Reed Bank.

China: Sinopec Exploration Southern Co. said it signed an agreement with ConocoPhillips for joint research regarding shale gas exploration, development, and production in Qijiang, Sichuan. This cooperation will be of great significance to the general evaluation on the exploration potential of the marine Paleozoic shale gas in the Southern Sichuan area and will help improve Sinopec's technology in the exploration and development of shale gas. The US Energy Information Administration estimates China has 145 trillion m³ of recoverable shalegas resources in Sichuan and Tarim basins. Financial details of the projects were not disclosed.

Indexes for selected refinery equipment items

Cost for six selected equipment items used in refining construction operations have been surveyed for three years (2010 - 2012). The accompanying table shows Nelson-Farrar equipment indexes for these items of equipment.

Valves and fittings showed the greatest increases in

cost, rising to 2,352.5 in fourth-quarter 2012 from 2,139.3 in first-quarter 2010.

Four other items showed more modest increases. The category bubble trays rose to 1,777.1 from 1,645.8 during 36 months. Tube stills increased to 675.6 from 623.1. Non-metallic building materials showed an index gain to 1,143.3 from 1,086.8. Fractionating towers showed a 75-point gain, increasing to 1,429.1 from 1,354 over the 3 years. The final category, tanks and pressure vessels, showed a mild gain during the data compilation period. The beginning index value was 1,133.8, while the final value was 1,171.1 (Table 5).

Quater	Bubble trays	Fractionating towers	Tube stills	Valves, fittings	Tanks, pressure vessels	Non-metallic building materials
2010						
1 st	1,645.8	1,354.0	623.1	2,139.3	1,133.8	1,086.8
2 nd	1,731.2	1,379.8	677.1	2,148.6	1,136.2	1,092.2
3 rd	1,692.5	1,373.6	647.6	2,163.6	1,140.4	1,091.6
4 th	1,716.1	1,382.0	654.8	2,157.0	1,136.8	1,088.6
Year	1,696.4	1,372.4	650.7	2,152.1	1,136.8	1,089.8
2011						
1 st	1,765.0	1,390.6	686.9	2,183.2	1,128.3	1,093.3
2 nd	1,829.5	1,405.1	729.8	2,218.8	1,122.9	1,105.7
3 rd	1,823.4	1,412.9	720.3	2,260.8	1,134.4	1,113.2
4 th	1,818.3	1,412.8	714.2	2,275.8	1,134.4	1,112.1
Year	1,809.1	1,405.4	712.8	2,234.7	1,130.0	1,106.1
2012						
1 st	1,827.3	1,421.4	719.0	2,314.1	1,143.4	1,128.8
2 nd	1,825.5	1,427.7	716.3	2,319.7	1,153.6	1,134.2
3 rd	1,789.8	1,419.4	685.7	2,339.4	1,150.0	1,141.8
4 th	1,777.1	1,429.1	675.6	2,352.5	1,171.1	1,142.3
Year	1.804.9	1,424,4	699.2	2.331.4	1,154,5	1.136.8

Table 5. Indexes for selected equipment items

Source: OGJ, 1 April 2013

