flow

25 years of multiphase subsea transport of oil and gas
– As well as improving the utilisation of resources on the continental shelf, multiphase research led to the development of subsea technology – a field in which Norwegian industry leads the world, with an annual turnover of 12.5 million euro.

– Its total benefits have never been calculated, but if I were to guess, I would estimate that the development of multiphase transport alone has created enough value to have paid for all the Norwegian research carried out during the past 20 years.

Johannes Moë, President of SINTEF when the Multiphase Flow Laboratory was built and came into operation.

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Kjell Bendiksen, President of the Institute for Energy Technology, and one of the fathers of OLGÂ, the software that was the key to multiphase subsea transport of oil and gas.

A quarter of a century ago, two Norwegian research institutes started to collaborate closely with Norwegian industry. From their efforts emerged a new technology that made it possible to transport oil and gas in a single pipeline over long distances on the seabed. In the language of the petroleum industry, this was ‘multiphase transport’.

Although the multiphase installations on the continental shelf are not visible to the general public, they have produced considerable economic benefits and have made a significant contribution to the development of Norway’s prosperity.

The development of multiphase technology demonstrates the importance of investing in research and development. Advances in this area have made it possible to produce oil and gas more efficiently and to develop fields that would otherwise have been impossible to operate.

The birth and adoption of multiphase technology demonstrate what a small country can achieve by setting up national technology teams. As early as the beginning of the 80s, the Institute for Energy Technology (IFE) had developed a preliminary version of its OLGÂ software package, which could simulate two-phase flow in pipelines. SINTEF contributed the results of its studies of multiphase flow, which were performed in the largest laboratory of its kind in the world. Combined with the expertise of the petroleum industry, this was of decisive importance for the success of the technology on the Norwegian shelf and elsewhere in the world.

The commercialisation of multiphase technology also triggered the development of a world-class Norwegian supply industry in this field.

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A valuable giant leap into the ocean

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At that time, and for several years to come, a separate platform needed to be installed on every single field wherever petroleum was being produced at sea. Norwegian multiphase research is one important reason that this is no longer the case.

New era at sea
The Multiphase Flow Laboratory in Trondheim was inaugurated on January 25, 1983 by Vidkun Hvending, Minister of Petroleum and Energy. In rural Tiller, on the south side of Trondheim, the guests could glimpse a network of shining pipework: 1000 metres of large-diameter steel pipe that ended in a 58 metre high concrete tower. A test facility that would help to change industrial history, as time would show, for the combination of OLG A software from IFE and SINTEF’s multiphase laboratory on the banks of the river Nidelva would be the start of a new era in offshore petroleum production.

Safer and cheaper
In collaboration with Statoil, IFE had developed the first version of OLG A three years ahead of the opening of the laboratory. With data from the large-scale laboratory in Trondheim, OLG A laid the foundations of a new technology that enabled the petroleum industry to carry untreated well flow – oil, water and gas – directly from the well to existing platforms on a neighbouring field, or all the way to the shore!

This is what professionals call multiphase transport, and it is an important reason why today’s petroleum industry can install entire production facilities on the seabed, leaving operating personnel ashore, where it is safer, cheaper and more environmentally friendly to work than on board platforms that depend on helicopter transport.

A major contribution to society
These new transportation arteries on the seafloor have saved the petroleum sector huge outlays. Multiphase technology has also made it possible to develop oil and gas fields that would otherwise have been unprofitable. All this means that the millions of kroner that were invested in the multiphase laboratory in Trondheim, the biggest of its kind in the world, have been paid back many times over.

The story of the building of the laboratory began when one of the world’s leading oil companies contacted the Norwegian authorities one day in 1979...
**To Norway – with best wishes, Esso**

“We would like to finance the world’s biggest laboratory of its sort, operate it on our own account for one year – and then donate it to the host institution of your choice.”

This was the content of an offer that Esso laid on the Norwegian government’s table in 1979. It arrived in the framework of what were known as the Technology Agreements; for an oil company to win a licence on the Norwegian continental shelf, at least half of the research carried out in connection with the field development must be done in Norway.

Geographical tug-of-war

Geographical tug-of-war ended in 1980 with the government resolving to locate the laboratory in Trondheim rather than Bergen. When it was decided, the head of SINTEF at the time, and a driving force for bringing the laboratory to the city. When he looks back today, the choice is quite certain: Esso’s invitation was decisive for Norway’s future as a petroleum nation.

**“Golden egg” from IFE and SINTEF**

If we don’t know what we are doing when oil and gas are sent on long trips together across the seabed, long slugs of liquid in the pipeline can be dangerous. The engineers realised that it would be expensive to test everything on the seabed, long slugs of liquid can come rushing through the pipeline on the final uphill stretch to the platform or onshore facility. In the worst case, they may overflow into the processing plant. Only studies can help. The engineers realised that it would be expensive to test everything on the seabed, long slugs of liquid can come rushing through the pipeline on the final uphill stretch to the platform or onshore facility. In the worst case, they may overflow into the processing plant.

A national technology team

As he looks back, he says multiphase technology is a good evidence of what the oil companies gained by signing forces with SINTEF (N) and IFE as a national team in this field. When it was established in 1979, the laboratory cost NOK 80 million (10 million euros). It was taken over by SINTEF in 1994. By then, why are in-depth multiphase studies necessary, before this technology can be deployed on the seabed? And why does the laboratory need to be so large?

**Leading simulations to deal with dangerous slugs**

Without in-depth research into the long-distance transportation of oil and gas in the same pipe, the receivers at the end of multiphase pipelines would risk finding long slugs of liquid in their laps.

Computer simulations to deal with dangerous slugs

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Nine oil companies financed a joint NOK 40 million (5 million euro) project that lasted from 1984 to 1986. When construction costs are included, the petroleum industry had invested no less than NOK 140 million (17.5 million euro) in Tiller and Kjeller by the end of 1986. Obviously, the need for multiphase transport was big in the oil industry. But why?

At the start of the petroleum era in Norway, only that oil close to a platform could be produced. All oil that lay close to a platform could be exploited using technology developed for shallow areas of the Gulf of Mexico. Fixed platforms were deployed in large numbers; they were relatively small, and were built of steel. In financial terms, building several such platforms on each field could be justified.

... to deeper waters

In the course of the 1970s, however, Norway began to develop fields in ever deeper waters, and huge concrete platforms began to appear. For these developments to be profitable, more of the field needed to be drained of oil and gas by each platform. The first answers to this challenge came in the form of horizontal drilling technology and the development of satellite fields with direct multiphase transport to existing platforms.

Feeding the dream

Multiphase technology makes it possible to exploit small finds where platforms would be too expensive, and carry the oil and gas in the form of untreated well flow to platforms that have spare capacity. Moreover, mixtures of natural gas and condensate (light oil fractions) can be taken ashore directly from the seabed installations on large offshore gas fields.

But OLG A had been born in an environment in which the scientists came from a quite different part of the energy world than the petroleum sector – and has its roots in nuclear power research

... and has its roots in nuclear power research

The concept of the OLG A computer simulation package was the brainchild of two IFE scientists, Dag Myhre and Kjell Berendes. In 1979.

In 1980, the first version of OLG A was already capable of simulating experiments with slugs that had been observed in sloping pipes in the USA. IfE had already been developing software for simulating the behavior of thermal and nuclear reactors for more than 20 years.

Statoil financed the development of OLG A at IFE for four years before the two partners agreed to continue the development process together with SINTEF in a major joint industry project, which was launched on January 1, 1984.

Industrial requirements

The task was divided up in such a way that IFE continued to develop OLG A, while the complement and scale of essential experiments were performed in Trondheim. This was the start of a close and fruitful 15-year collaboration between SINTEF and IFE, which is now also built into OLG A.

The fact that the two biggest Norwegian centres of research in this area had joined forces gave them considerable combined power. Together, we defined and prioritised the experiments in Trondheim on the basis of both industrial and technological requirements. The potential for developing OLG A was always the basis of the design of new experiments in the laboratory in Trondheim, says Kjell Berendes, who became president of IFE in 1995.

Practical tool

The aim of OLG A was to develop a practical industrial tool. Inducing needed a tool that could calculate important properties such as production rates, pressure and fluid content, through the entire transportation system. OLG A needed to be able to predict whether the flow would stabilize, or whether it would cause a risk of dangerous instabilities, explains Berendes. IFE has been continuously improving OLG A throughout the 10 years that have passed since the concept originated. In 2008, IFE was awarded Statoil’s research prize for its efforts in multiphase research.

The man who won the Statoil's research prize 15 years prior is the result obtained by the Norwegian pioneers in multiphase research –...
Launch help from the father of petroleum nation Norway

Multiphase technology was soon given high priority as an area of special effort by Statoil’s management, confirms Arve Johnsen, the first head of the company.

As the first head of the company, Johnsen was actually Statoil’s sole employee when it was set up. In 1972, he installed himself in a rented office in Stavanger with the company cash kept in a little cigar box. Fifteen years later, when he retired, Statoil was one of Norway’s biggest industrial companies – and one of the world’s biggest offshore oil companies.

Important interactions

Arve Johnsen points out that a large number of different technologies made the Norwegian oil industry possible. And that is impossible to rank them in order of importance. They are all interconnected, he points out, and mentions as an example the close interactions between technological developments in multiphase transportation and subsea production.

Subsea technology is a method of production that, nowadays characterises not only the Norwegian continental shelf but also the Gulf of Mexico, Angola and the Brazilian shelf,” he says. Subsea multiphase technology is an example of transferable research from laboratory to the platform in national and international petroleum history.

The end of the 1980s:

For the first time in history, gas was pumped from one field to another in order to recover more oil from a reservoir.

OLGA was also utilised in the design of the TOGI project. As Hårold’s project director, Magne Boge, says to Geimini in 1989: “In the TOGI project, we have utilised 100 percent of the results that emerged from the multiphase flow laboratory in Trondheim. The OLGA program, which we adapted for use in TOGI, was not the least decisive input for the development of the concept.”

The OG A program, which was not least decisive input for the development of the concept.

Value as cultural history

In 2002 the project came to an end, and the pipeline was closed down. The State Antiquary points out that the closure plan ought to include a study of the value of the installations’ cultural value. By then, OG A had already helped to save millions of kroner in the neighbourhood...
That was the day on which production started on the Troll field west of Bergen. Norway became one of Europe’s most important gas suppliers for the coming century.

With Troll, Norway inaugurated its first multi-phase transportation system which carried gases and condensate from the North Sea to the shore. A stretch of 67 km that crossed the Norwegian Trench Troll well flowed into a well which was removed on the platform, was sent directly to Kollsnes near Bergen, which meant that the offshore processing plant could be dramatically smaller than it otherwise would have been. The operators were thus able to avoid the more expensive solution, an even larger Troll platform. Operating costs were also cut, because the needs for manpower and thus accommodation and food of men at sea were much lower.

Almost NOK 46 billion saved

At a press conference in 1989, Norske Shell, the operator, said that splitting the Troll project between offshore and onshore plants would reduce development costs by NOK 4.5 billion (570 million euro), and cut annual operating costs by NOK 330 million (40 million euro).

The Troll field will produce gas for 75 years. Over the lifetime of the platform, multiphase technology will thus be responsible for savings of almost 30 billion 1969-kroner (nearly NOK 46 billion (5.7 billion euro) in 2009 terms). And that is on Troll alone!

But almost at the same moment as the gas was beginning to flow in from the Troll field, dark clouds were beginning to gather over the Tiller laboratories...

Troll can be tamed

On February 9, 1996, a gigantic gas-field dominated the news in Norway. Here too, multiphase technology and OLGA played important roles.
By now, the oil companies had used OLG A in many field developments; they had acquired operating experience and could compare the results of OLG A simulations with field data. Many of these companies found that OLG A was good enough to deal with the challenges they faced, and they claimed that it would be too expensive to continue tests on such a large scale as that offered by SINTEF. After 13 full operations, the kilometre-long pipe-loop was decommissioned.

From large- to medium-scale

For OLG A to become even better, other types of experiments were needed. The necessity for more detailed studies of flow also required more advanced instrumentation. In 1985, in parallel with the tests carried out at Tiller, IFE built a medium-scale experimental facility that was aimed at improving our understanding of multiphase flow phenomena. In collaboration with SINTEF and Statoil, IFE built a medium-sized multiphase rig in 1994 to improve OLG A’s ability to simulate flows in deviated wells, and in 1998, SINTEF upgraded a younger brother of the large-scale loop. More water in pipelines may also cause ice-like crystals called hydrates to form in the oil and gas flow. IFE and SINTEF also tackled this problem. The risk of hydrate formation is greatest when production on a field is shut down, for example for maintenance. Without countermeasures such as using anti-freeze, heating or other solutions, hydrate plugs can lead to expensive operating shut-downs or, in the worst case, permanent blockage.

The increasing amounts of water that were being produced by ageing oil fields were at the focus of the medium-scale experiments. Large volumes of water flowing through a pipeline can bring in their wake a number of problems, including corrosion. Internal corrosion can occur suddenly and may have very serious consequences, in the worst cases leading to leaks. IFE’s response to this problem was to spend years developing methods and chemicals, known as inhibitors, to counteract corrosion. More water in pipelines may also cause ice-like crystals called hydrates to form in the oil and gas flow. IFE and SINTEF also tackled this problem. The risk of hydrate formation is greatest when production on a field is shut down, for example for maintenance.

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Without countermeasures such as using anti-freeze, heating or other solutions, hydrate plugs can lead to expensive operating shut-downs or, in the worst case, permanent blockage. And while the industry was equipping itself for the conditions awaiting it in these pitch-dark waters, a new report brightened up the lives of OLG A’s parents…

Crisis – and new potential

In 1996, the biggest multiphase laboratory in the world suddenly became too big!

The report “Value Creation through Technology” was drawn up by Conoco Norge. Between its covers, the company described how it had calculated the value created by a selection of R & D projects performed between 1979 and 1996. OLG A was one of four projects chosen as “The Greatest Success Stories,” and the report received wide coverage in the business and industry press. In current kroner, Conoco had put NOK 560 million into Norwegian research and development (NOK 1.3 billion 1999 kroner - 160 million euro), which went to 318 projects. Part of that sum went into the research that eventually materialised in the shape of OLG A. Conoco was one of several oil companies that financed these efforts.

For its calculations, Conoco Norge selected 64 of the 318 projects. The company’s conclusion was that these projects alone had saved it some NOK 3.6 billion (450 million euro), or four times the amount the company had invested in all its R & D in the course of 20 years. The report also estimated that the savings made by other companies came to NOK 12.3 billion (15 billion euro).

A cautious estimate

“We looked at what projects can offer in terms of pure cost reductions, without counting the gains in increased oil and gas production, so the total value created by these projects has been even greater,” said research director Ole Lindютjeld at the launch of the report.

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New challenges ahead

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This was the challenge that awaited the multiphase engineers at the turn of the century. The coming of the 21st century announced a need for new technology on the continental shelf. Shitokman gas and heavy oils

Future multiphase pipelines will be designed to stretch from great depths across long distances to shore and up steep slopes on the seabed. Many of these systems will carry heavy oils, and several will probably be laid in the Arctic. The giant Shitokman gas field, 550 kilometres north of Russia, and several other developments, place heavy demands on multiphase systems, which require more accurate simulation models. This is why the petroleum sector now has launched several major new research projects.

Celebrated ‘lady’ meets a challenger

At the beginning of the new century, OLGA had long been a celebrated ‘lady’, with a share of almost 90 percent of the global market for design and operating software for offshore multiphase systems. Many of the challenges that were queuing up on the seabed, SINTEF took an initiative that will provide OLGA with a challenger.

In 2002, in collaboration with ConocoPhillips Norge and Total Norge, SINTEF started to develop LEDA, a computer simulation tool that will offer detailed images of flow conditions in parts of the pipeline that users can zoom in on.

As part of the LEDA project, the large-scale laboratory was reopened in 2001. The Tiller laboratory was also enlarged with a hall for medium-scale experiments and an explosion proof bunker in autumn 2009.

These new facilities will be used to study interactions between flow regimes and the surface chemistry of oil droplets, an important topic when heavy oils are to be transported in multiphase pipelines.

Together with STPGroup, Statoil, Chevron, ExxonMobil, ENI and Shell, IFEl launched a project that will completely renew OLGA via a new generation of multiphase models that depend on basic physical principles.

While OLGA is based exclusively on relationships that had been observed in the course of laboratory experiments, HORIZON is developing a detailed mathematical model that reproduces the physical world more accurately than OLGA.

Multidisciplinary team

The aim of the LEDA and HORIZON projects was to develop pipeline systems with greater transport capacity and reduced risks of breaks in operation. Norwegian research institutes put large multidisciplinary teams on the job.

While LEDA was gradually being fleshed out, OLGA was adopted by the two development projects that formed Norway’s most important arenas of innovation at the turn of the century:...
From the two huge gas fields, natural gas and condensate flow directly from the seabed installations to their onshore terminals. Snøhvit, the pioneer

The multiphase pipeline that links the fields in the Snøhvit project with the island of Mekøya near Hammerfest is 143 kilometres in length, a record distance for pipeline transportation of untreated well-flow! The Snøhvit terminal on Mekøya is Europe’s first export plant for liquefied natural gas (LNG).

"Long-term strategic efforts on the development of multiphase technology were an important prerequisite for Snøhvit, the first field development in the Barents Sea,” says information manager Sverre Kojedal in StatoilHydro.

"The well flow from Ormen Lange is separated at Nyhamna in Aukra municipality in the County of Møre og Romsdal. The natural gas is sent on to the UK through Langeled, the longest subsea gas pipeline in the world. Foto: StatoilHydro"

At the top on the bottom

With OLG A playing a supporting role, the Ormen Lange and Snøhvit gas fields came on-stream in 2007. These were the first major field developments on the Norwegian shelf that were based on neither production vessels nor platforms.

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Special efforts to overcome production barriers

The aggressive conditions on the outside of the multiphase pipelines of the future have led SINTEF/NTNU and IFE to tread new ground in order to prevent complications inside the pipes.

"Cold Flow" is the newest research result. The philosophy is based on tolerating ice-like crystals that can form within the pipeline. If they stay inside, they may rust. The wall of the pipe is reduced in capacity, and the long distances at great depths, a number of problems can occur. Ice-like hydrates can plug the pipeline, and the water droplets are normally enclosed within the hydrate crystals. As a result, the hydrates resemble powdery snow. And as all Norwegiansknow, this snow never turns into snowballs.

"ICE" THAT BURNS: No, this is not ice, but hydrates, ice-like crystals that can form within the pipeline. And as all Norwegians know, this snow never turns into snowballs.

When untreated well flow is transported over long distances at great depths, a number of problems can occur. The hydrates can plug pipelines, wax may be deposited on the inside wall and reduce its capacity, and the pipe may rust.

"Cold Flow" is a new "Cold Flow" became a well-known concept as the new century, a new way of thinking in the war against hydrates in multiphase pipelines. The philosophy is based on tolerating hydrates instead of removing them. The recipe is to create conditions within the pipeline that make the hydrates resemble dry snow instead of slush.

With the Cold Flow method, water and gas molecules grow into tiny round snow particles with cold water becoming enclosed within the crystal. As a result, the hydrates resemble powdery snow. As all Norwegians know, this snow never turns into snowballs.

An "age" for hydrates

Independently of SINTEF’s work on Cold Flow, IFE and the SPT Group continued to develop OLGA in their HORIZON project, which aims to calculate where hydrate particles occur and grow within the pipeline. Do they attach themselves to the pipe wall, or do they aggregate themselves with other particles and grow larger? Do they flow along with the water or the oil?

Problems of this sort form part of the background for the Multiphase Flow Assurance Innovation Centre (FACE), a national centre for research-based innovation, which is hosted by IFE, in cooperation with SINTEF and NTNU.

The world’s biggest supplier of subsea technology, the global corporation FMC Technologies, has more than 3000 employees in Norway. The Norwegian part of the group has developed robust, reliable products that are already placed on the seabed. The other is that we understand how unprocessed hydrocarbons are capable of flowing over long distances; in other words, we have a good understanding of multiphase technology.

Two experts explain why the subsea sector has grown as much as it has done. One is that we have developed robust, reliable products that are already placed on the seabed. The other is that we understand how unprocessed hydrocarbons are capable of flowing over long distances; in other words, we have a good understanding of multiphase technology.

Subsea – in the middle of Norway

The subsea sector in the inland city of Kongeberg started with Kongsberg Varhaug. One of the former state-owned companies, which had been wound up, rose Kongsberg Varhaug AS, which is now part of FMC. The Houston-based group develops technology for both surface and subsea field developments. In the Norwegian part of the company, however, everything has to do with seafloor technology. And FMC’s subsea boss is quite certain that the subsea industry’s operations are based on breakthroughs in multiphase technology.