The Esso Energy Award Lecture, 1998. Boosting production from low-pressure oil and gas fields: a revolution in hydrocarbon production

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The Esso Energy Award Lecture, 1998
Boosting production from low-pressure oil and gas fields: a revolution in hydrocarbon production

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World population is rising at a rapid rate and the need for energy is increasing, particularly by the highly populated developing countries. Oil and gas form at present 63% of the total world primary energy demand. The proven world reserves for oil and gas, although relatively high, will not last more than 41 years (oil) and 64 years (gas), on average, if production continues at its present level. The proven oil reserve to production ratio (R/p) for Europe is much lower and is close to 8.2 years. There is therefore a need for this valuable source of energy for the foreseeable future.

The low price of oil is causing the development of many marginal oil and gas fields to become uneconomical. The response to this challenge is to achieve cost-reduction, improve recovery from the fields and to take strategic steps to survive and improve profitability.

The production and total recovery from many fields can be enhanced by using a boosting system downhole or at wellheads for production systems located subsea, offshore or onshore. The cost of some boosting systems is, however, relatively high, making them uneconomical.

Factors such as fragmentation of reservoir or production from satellite fields result in some wells having high pressure, while others may have low pressure with restricted production. A team of engineers at CALTEC have developed a simple cost-effective system which uses energy from high-pressure wells to boost production and recovery from low-pressure wells. The system is patented by CALTEC and is named 'WELLCOM', short for 'well commingling system'. The main advantages of the system are: increase in production and revenue; simplicity; having no moving parts; low capital cost, with the payback achieved often within a few weeks or months from the added revenue. A further benefit of the system is that it uses the energy from high-pressure wells that is usually wasted through choke valves.

This paper describes the system, the background to its development, its performance and applications. A team of engineers from CALTEC won the Royal Society's 1998 Esso Energy Award for the development of the WELLCOM system.

Keywords: multiphase pumping; WELLCOM; jet pump; boosting production; ejectors; eductors

1. Introduction: the need for oil and gas

Before introducing the WELLCOM system and its applications, it is perhaps apt to take a look at oil and gas as a primary source of energy.

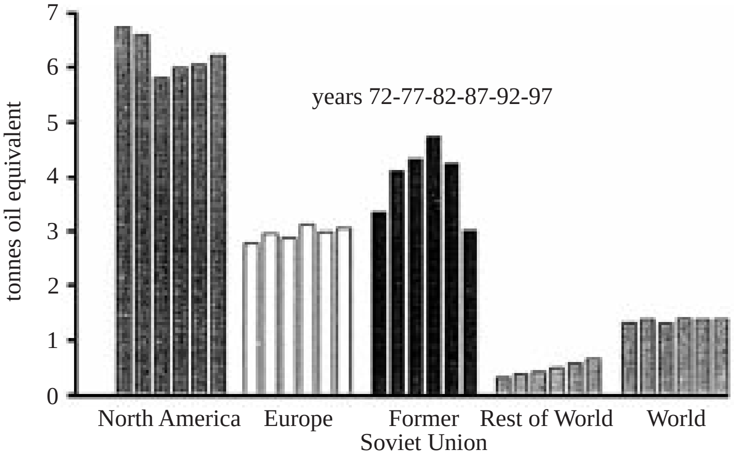


Figure 1. Energy consumption per capita (from BP 1998).

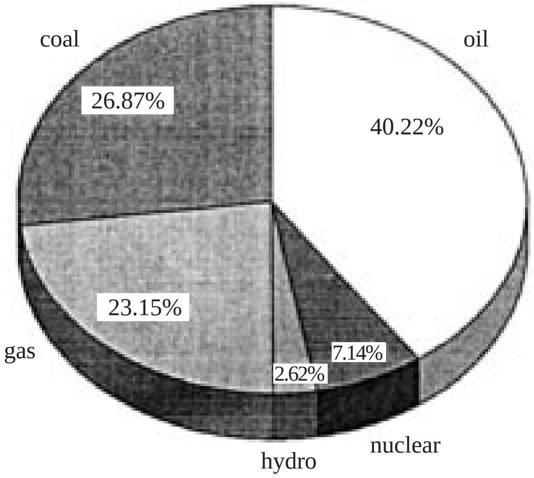


Figure 2. World primary energy consumption (MTOE) (from BP 1998).

The need for energy is increasing at a rapid rate. This is caused primarily by the increase in world population and the rise in the standard of living in most of the highly populated and developing countries. For many people in the world, the need for energy is still a matter of survival, while for others it is to maintain a reasonable quality of life and, for a few luckier nations, it is to maintain a level of affluence.

World population is expected to reach 80 billion by the year 2020, which is double the 1980 figures. Figure 1 shows the energy consumption per capita for the various parts of the globe, and shows the alarming lack of parity. Rapid increase in population and energy consumption in the developing and highly populated countries, which are grouped as the ‘rest of the world’, is expected to raise their average energy demand to nearly three times the rate of growth in OECD countries. The total world energy demand is therefore expected to be nearly doubled by 2020, compared with 1975 figures (Luding 1994).

A look at the world primary energy consumption (figure 2) shows that oil and

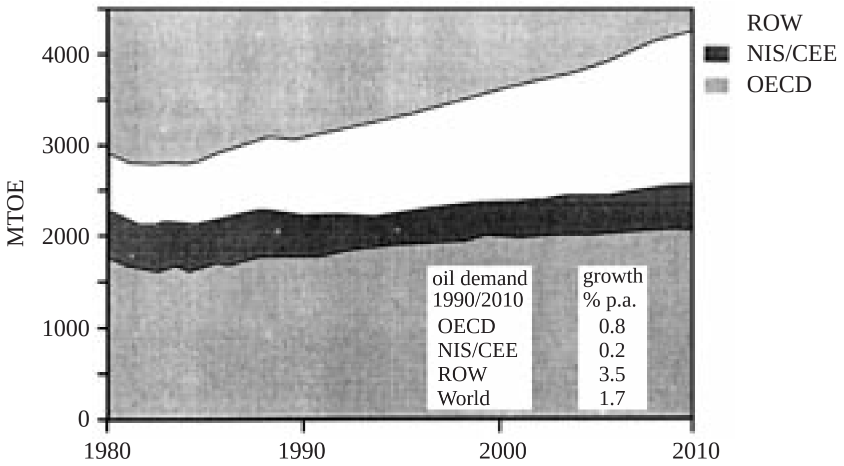


Figure 3. World oil consumption (source: International Energy Agency): 141 million tonnes (1038 million barrels) (from BP 1998).

gas form close to 63% of the total energy demand, with oil being 40% of the total primary energy. It is worth noting that, despite advances in technology and efforts made in developing the greener alternative renewable energy sources such as wind, wave and thermal energy, their total contribution to world energy is just 3.7% and, if hydroelectric power is included as the additional renewable energy source, the total reaches a mere 6.1%. It is therefore unlikely that, in the foreseeable future, the supply of other sources of energy will become significantly more economical and increase at such a dramatic rate that the demand for oil and gas would reduce to a great extent. The pattern shown in figure 3 for the rise in oil consumption by the year 2010 may well materialize, reaching a total of 4250 million tonnes from the current annual 3475 million tonnes (1997). This means that the daily production rate should rise from the current 72 million barrels per day to almost 92.5 million barrels per day by then. The world's oil is primarily concentrated in the Middle East, which supplies 30.1% of the total world production. Europe supplies only 9.4% of the total, compared with the consumption rate of 22.1%. A similar story applies to North America, where production is 19.2% of the total world oil, compared with the consumption, which is close to 29.6% of the total world value (BP 1998).

(*a*) *Fuels paradise?*

Total proven reserves of oil in the world at present exceed 141×10^6 t (1038 million barrels), with the Middle East holding 65.2% and Europe a mere 1.9% of the total (figure 4). Gas-proven reserves follow a similar pattern with the Middle East holding 33.7% and Europe only 3.8% of the total.

These numbers look impressive in total, but the overall picture changes if we work out simply how long these reserves will last if we continue consumption and production at the present rate. Figures 5 and 6 show that, with the exception of the Middle East, reserves over production rates (R/P) are indeed very low, with Europe's R/P for oil being as low as 8.2 years. The average value for the world as a whole is not so promising either, and is only 40.9 years for oil and 64.1 years for

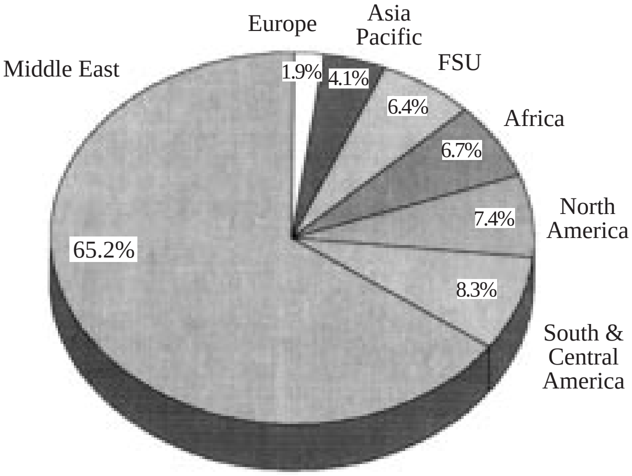


Figure 4. World oil reserves.

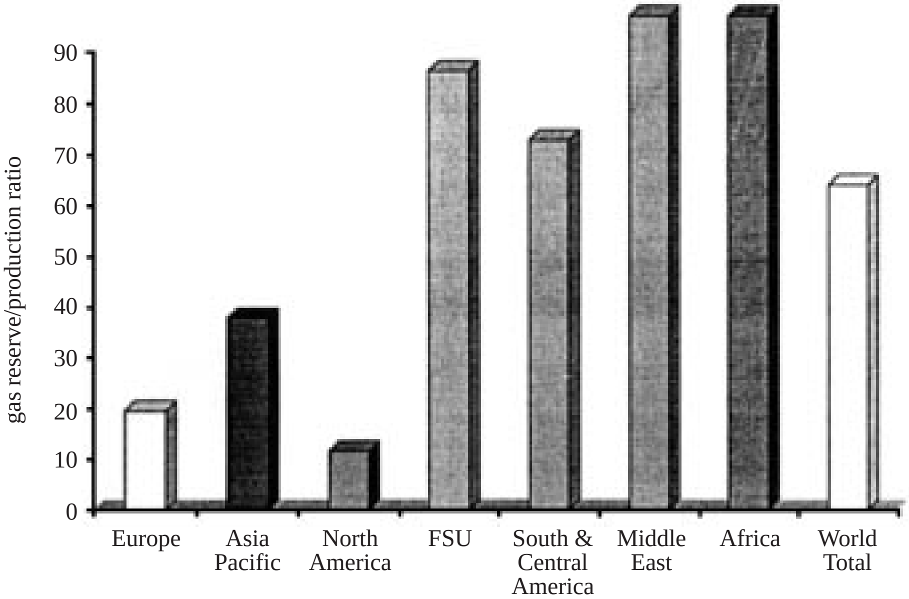


Figure 5. Gas reserve/production ratio (from BP 1998).

gas. These periods are alarmingly low, and show that we are not, indeed, living in a ‘fuel’s paradise’ as it appears.

The above numbers are bound to be changed by various events, and forecasts, as often shown in the past, could be inaccurate. Whatever the level of error and whatever the increase in proven reserves in future, the overall picture is not expected to change dramatically. The message is therefore to take steps which will help to alleviate the oil shortage in the 21st century. These goals can be achieved by

(a) conserving energy and reducing wastage;

(b) improving efficiencies wherever energy is converted and consumed;

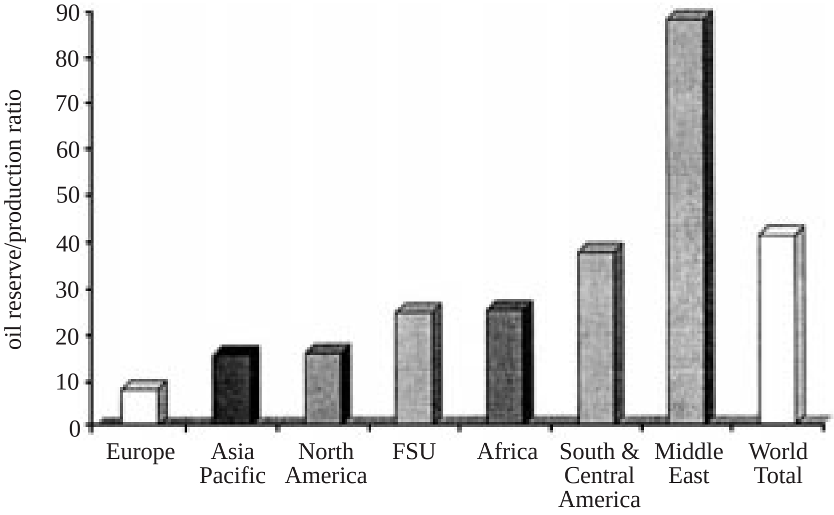


Figure 6. Oil reserve/production ratio.

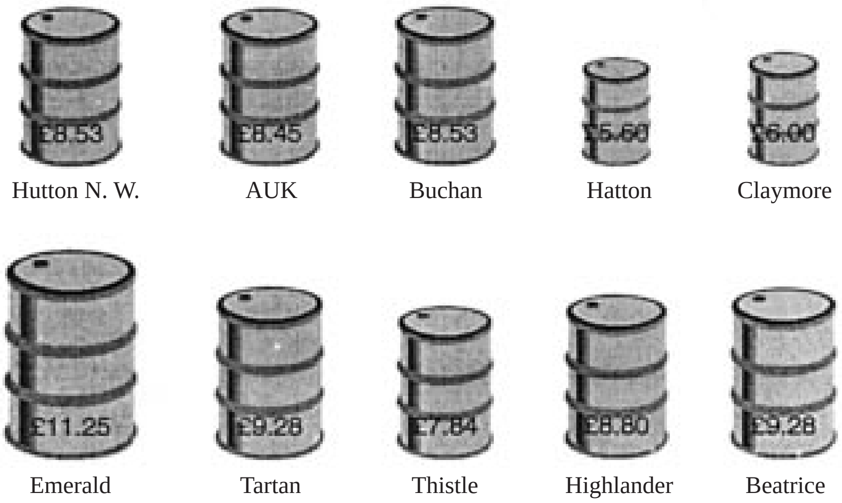


Figure 7. Required price of oil per barrel for field economics.

(c) intensifying and improving the economics and methods of harnessing other forms of energy;

(d) improving techniques for prospecting and exploration for oil and gas;

(e) improving the production efficiency and total recovery from oil and gas fields.

It is worth noting that, despite the advances in technology, the average rate for recovery of oil from existing reservoirs is only 35% of the total reserves. In some fields with good reservoir management and use of new secondary and tertiary recovery techniques, the rate has risen to 40% or even 60%. Improving the total recovery rate is certainly an effective way to extend the life of oil and gas fields and the supply of energy. Extracting the additional oil and gas at the end of field life when the reservoir

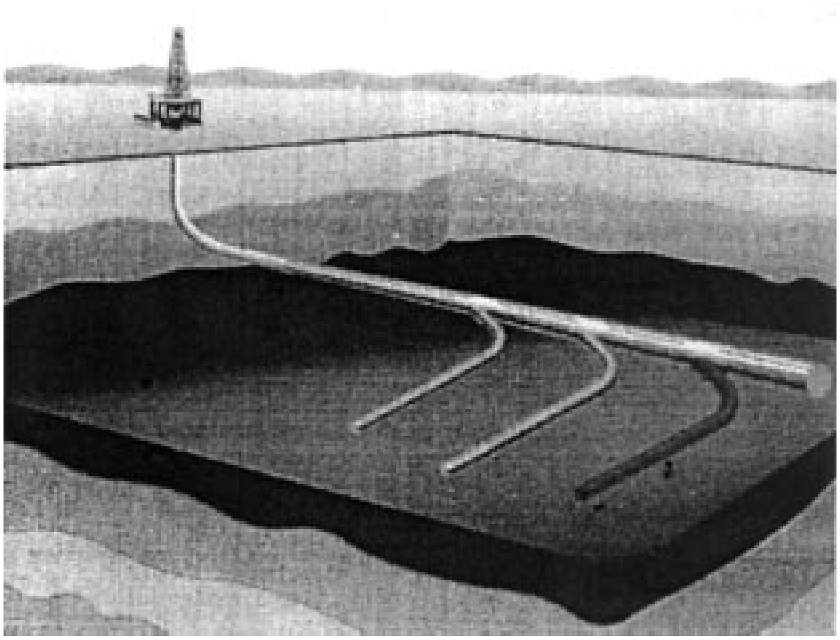


Figure 8. Horizontal well with multi-laterals.

pressure has been depleted is no easy task, and for some fields the WELLCOM system discussed in this paper is one way to achieve a part of this objective economically.

2. The price of oil factor

The total oil and gas production rates in the world exceed the demand at present, causing a significant drop in their price despite the alarming short-term availability of these valuable sources of energy. A key contributor to this temporary situation is the desperate need by most major oil-producing countries to increase their revenue in order to meet their demands for development and planned expenditure.

In most Middle Eastern countries, oil constitutes 80–97% of their export and it is clear how dramatic the effects of restricting production or a drop in the price of oil could be on their economy. It is also worth noting that at present the so-called world excess level of available production compared with demand is only 3% of the total consumption, which is not a big margin at all!

For many small fields located offshore, in deep waters or remote areas, the capital and operation costs of producing oil and gas are high. A drop in the price of oil will therefore affect the economic viability of many fields in this category. Figure 7 was published in 1994, showing the minimum price of oil needed to make the economics of production from these fields in the North Sea viable. A similar fact applies today, where the development of many offshore fields relies on the price of oil being above \$10 to \$12 per barrel.

A remarkable fact is that oil at \$12 per barrel (£7.5 @ £1 = \$1.6) translates to 4.71 p per litre! We pay nearly 47 p per litre for the natural bottled water we purchase from our supermarkets. This is nearly 10 times the price of oil despite it being only

H_2O! The price of oil becomes, of course, heavily distorted when government taxes in excess of 80% are added.

Perhaps worse than the low price of oil, the chaotic fluctuation in its price has a more damaging effect on the oil and gas industry. This is because the economics of field development changes dramatically as the revenue changes, thus affecting its profitability. These changes and uncertainties also discourage the development of new fields if the profit margin is low or even negative, with the added risks associated with the reservoir behaviour against high capital expenditure and investment.

3. Challenges facing the oil and gas industry

The low price of oil is not the only problem which the oil and gas industry faces. The development of many fields poses one or more of the following challenges which the operating companies have to cope with while achieving an acceptable rate of return for their investment, risks and endeavours:

- limited reserves;
- low pressure or rapid decline in pressure;
- fragmentation of reservoir;
- many new fields stranded and far away from existing infrastructures;
- deep water production, with the associated added costs;
- production of heavy and viscous oil;
- production of so-called nasties, such as H_2S, CO_2, wax, sand and scale formation;
- production of water and its rapid increase during the field life;
- coping with safety and environmental issues which add to the capital and operation costs.

All the above add to the capital and operation cost of fields in some way, and could make their development or the continuation of production near the end of field life uneconomical.

The industry has been active in responding to these challenges. The improvement in the profitability has been achieved mainly by one or more of the following actions:

- cost reduction;
- improved production and recovery;
- strategic policies, such as mergers, alliancing, acquisitions, risk-sharing and streamlining activities.

In all cases, innovation has been the key factor in achieving most of these objectives. Take the example of horizontal and multi-lateral wells. Conventional vertical or deviated oil wells can only capture oil from a limited part of the reservoir, particularly if the rock permeability is poor and the production zone is thin or the

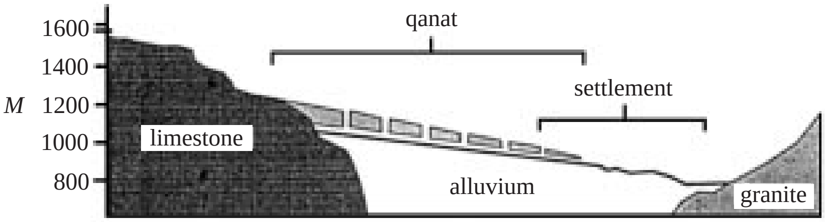


Figure 9. General configuration of a qanat.

Figure 10. Aerial view of a qanat.

reservoir is fragmented. Horizontal wells, on the other hand, penetrate far into the production zone and cover a large part of the reservoir (see figure 8). The productivity of these wells is, therefore, much higher than for vertical wells and they enable a smaller number of wells to be drilled for optimum production and recovery from each field. This novel technique took nearly 15 years to develop and establish itself in the industry. The concept is, however, not new and, surprisingly, dates back to 700 BC! The 'qanats', or underground horizontal canals, which were developed and used by Persians during the Achaemenian dynasty in ancient Iran, use the same principle, and enable water to be collected via long horizontal channels. These wells cover a vast area stretching from the foothills of the mountains to the towns and dwellings in flatter areas (see figures 9 and 10). These qanats are simple to construct and maintain and are still being used as the most efficient way of supplying water in arid areas. The shallow vertical boreholes are, in this case, mainly for access during construction and for maintenance purposes.

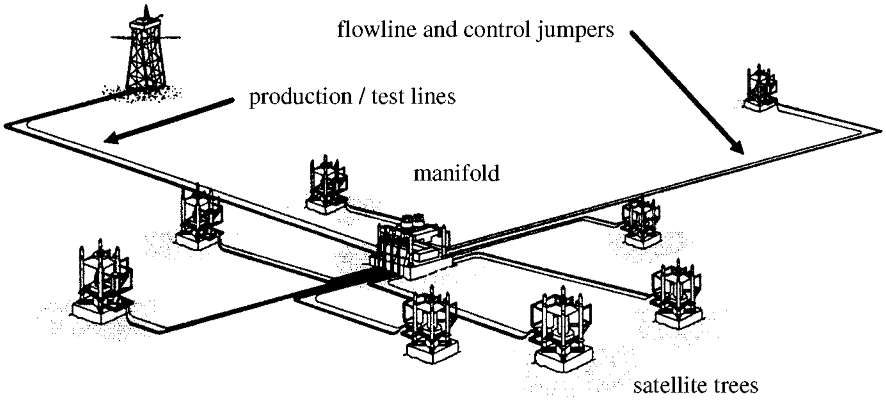


Figure 11. Typical field with subsea manifold and satellites.

4. Challenges in production and transport of fluids

The oil and gas found in reservoirs deep below the ground or below the seabed need to be transported safely and efficiently to a production facility for processing. Transport of oil and gas from the reservoir to a plant requires sufficient energy. The fluids flow within the reservoir through the wellbore, pipelines and risers (offshore) to a process plant and along their path, loss of pressure is caused by friction and the hydrostatic head of produced fluids. Sufficient energy is therefore needed to compensate for these losses and to deliver the products at a pressure dictated by the processing plant and the gas handling and transportation requirements. Low reservoir pressure, or the drop in reservoir pressure during the life of the field, results in restricting production and, in some cases, abandonment of the field. Boosting systems are often required to maintain production and to compensate for the said losses. Typical boosting systems are gas lift downhole to reduce the hydrostatic head of the fluids within the wellbore, downhole jet pumps, downhole electric submersible pumps and the new generation of multiphase pumps at the wellhead which can handle a wide range of gas–liquid mixtures.

The selection of the suitable boosting system is often dictated by the economics involving both the capital and the operation costs of these systems compared with the gain in production and the added recovery achieved from the field. Boosting systems such as multiphase pumps or downhole pumps are not used in some fields, mainly because of the associated high capital and operation costs.

Figure 11 shows a typical field with satellite wells where production from several wells is gathered into a manifold system. The manifolding of products enables the number of costly pipelines and risers required for the transportation of produced oil and gas to be minimized. Fragmentation of reservoir, production from different zones or satellite wells often results in wells having vastly varied production characteristics and different flowing wellhead pressures. In these cases, the production from low-pressure (LP) wells is often restricted, or sometimes impossible, because of the back pressure imposed by the high-pressure (HP) wells or the downstream pipeline pressure. Traditionally, the high-pressure wells are choked down (using choke valves) to minimize the back pressure on LP wells whenever the products are manifolded. This is a waste of energy and it is indeed this energy which is put to good use by the

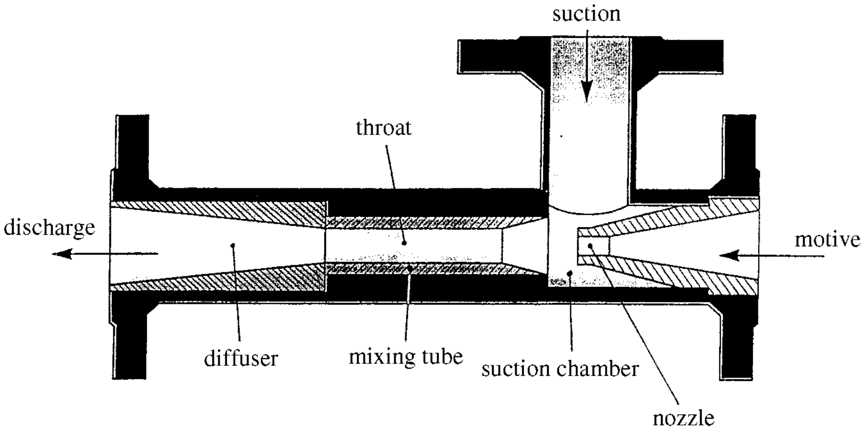


Figure 12. General configuration of a jet pump.

'WELLCOM' system, which uses jet pump technology, to transfer energy from HP wells in order to boost the pressure of LP wells and to increase their production.

5. WELLCOM system/jet pump technology

Jet pumps are a simple and reliable device for transferring energy from a high-pressure fluid to a low-pressure fluid. The general configuration of the jet pump is shown in figure 12. High-pressure fluid passes through a nozzle where part of the potential energy (pressure) is converted to kinetic energy (velocity). As a result, the pressure of the HP fluid drops significantly downstream of the nozzle. It is at this point where the LP fluid enters the jet pump. The mixture enters the mixing tube where transfer of energy between the HP and LP fluids takes place. The fluids then pass through a diffuser where the mixture velocity is reduced gradually and further pressure recovery is achieved. The pressure at the outlet of the jet pump will be at an intermediate level between the pressure of HP and LP fluids. By using the jet pump, the LP flow is no longer exposed to the back pressure imposed by the HP fluid or the downstream pipeline, and the low pressure created downstream of the nozzle enables the LP flow to continue at this lower pressure. In oil and gas wells this drop in LP pressure means an increase in production as the production profile in figure 13 shows.

Jet pumps are not new and date back to 1852 in England, with J. Thomson believed to be the inventor. Records show a patent by Crocker and Angier in 1864. In 1930, six patents were granted for their application in oil production downhole. This was followed by the publication of the theory in 1933 by Goslin and O'Brien. Since 1970, there has been extended downhole use of the unit, where both the motive and suction flow are a liquid phase. Jet pumps, also known as ejectors or eductors, have been used in other industries for commingling two fluids of different pressure. However, in all cases the jet pumps operated in a single phase where both HP and LP fluids were gas (or steam) or a liquid phase. In these industries the boost in the LP pressure was also less important compared with the demands of the oil and gas industry where the rise in the mixture pressure downstream of the jet pump is desired to meet the pipeline and transportation requirements.

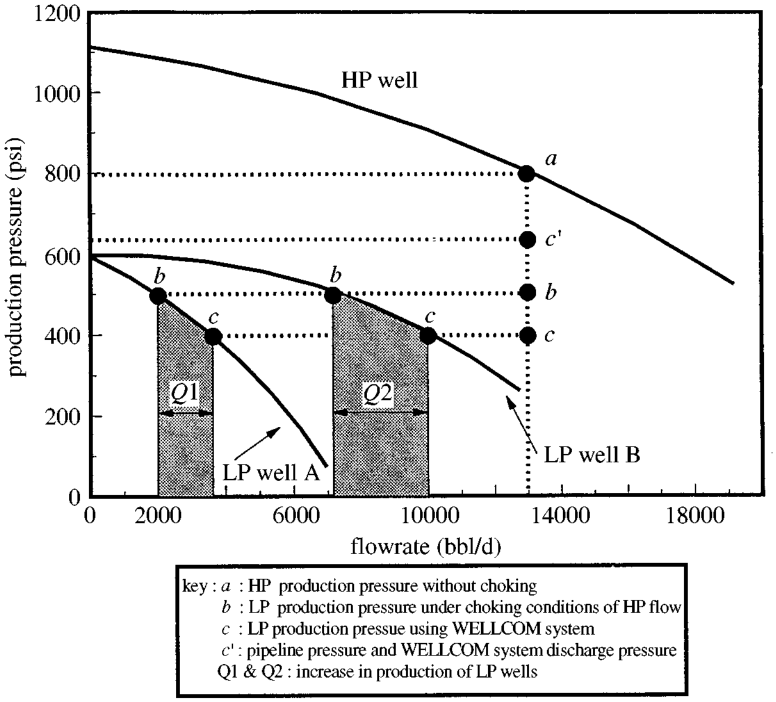


Figure 13. Effects of WELLCOM system on production.

The application of jet pumps in the North Sea for gas production dates back to 1985 when CALTEC (BHR Group) developed and designed two units that were installed on two platforms for the Hewett field, North Sea. These jet pumps increased production by 25% and 41%, respectively. The payback period was achieved in less than four weeks. CALTEC supplied a further jet pump for Agip's Spilamberto field near Bologna, Italy. This jet pump enabled to bring a non-productive abandoned well back to life, achieving a production rate of 21 000 Nm^3 per day gas. This jet pump also paid for itself in about three weeks. The good experience achieved encouraged Agip to install a further six units successfully onshore and offshore which extended the life of gas fields and the total recovery by using a low capital, simple and reliable system with no operating cost. During this period CALTEC, as a result of extensive laboratory tests, succeeded in improving the design and efficiency of these jet pumps and developed a computer model for their optimum design and for predicting their performance.

6. Jet pumps handling multiphase flow: WELLCOM system

In oil production, the produced fluids consist of gas, oil and, in many cases, water. Often some liquids (condensate or water) are also produced in gas production applications.

The nozzle of the jet pump, which is one of its key components, does not function efficiently when a mixture of gas and liquid passes through it. Furthermore, there are subtle differences in the design and performance of the system handling multiphase flow. These issues led to the development and patenting of the system

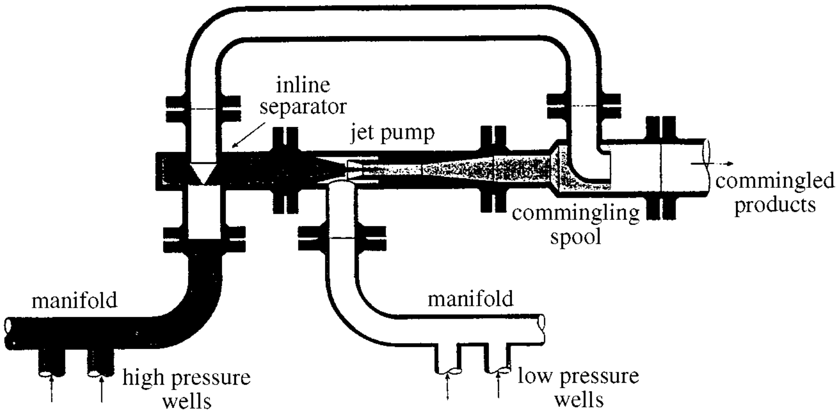


Figure 14. General configuration of WELLCOM system.

named WELLCOM, which helps to solve the problem of handling multiphase flow by a jet pump. This system was then registered by CALTEC under the trade name of 'WELLCOM$^{(\mathrm{TM})}$' (short for 'well commingling' system).

The WELLCOM system is shown in figure 14. This system consists of three main components: a compact inline separator, a specially designed jet pump and a commingling spool. The separator, known as WELLSEP, separates gas from the multiphase HP mixture and enables the HP liquid phase to be fed into the jet pump as the motive flow. The specially designed jet pump takes the full LP multiphase mixture on its suction side, and the separated HP gas is combined with the mixture from the outlet of the jet pump.

7. Development and field trials

A prototype unit was designed, manufactured and extensively tested during 1994 in CALTEC's laboratories. These tests were successful and proved the viability of the concept. During 1995, the second phase of development, a full-scale model was manufactured and tested, using a specially designed test rig in Peterhead near Aberdeen. An air–water mixture under pressures of up to 20 bar was used for the tests. The trials were successful and led to the third phase of the project which involved testing a full-scale unit in Agip's Trecate field, near Milan, Italy. The Trecate field enabled the system and its key components to be tested under a full range of operation conditions with the motive HP flow supplied directly from the nearby wells or from the test separators. Use of real hydrocarbon under representative field operation conditions was essential in order to demonstrate the performance of the system.

8. Performance of the system

Figure 15 shows the photograph of the full-scale skid and the key components of the system which were field tested extensively. Typical operating conditions and the results of some tests are shown in figure 16.

The performance and the efficiency of the multiphase jet pump, which is the key component of the system, are shown by dimensionless numbers N and η described in

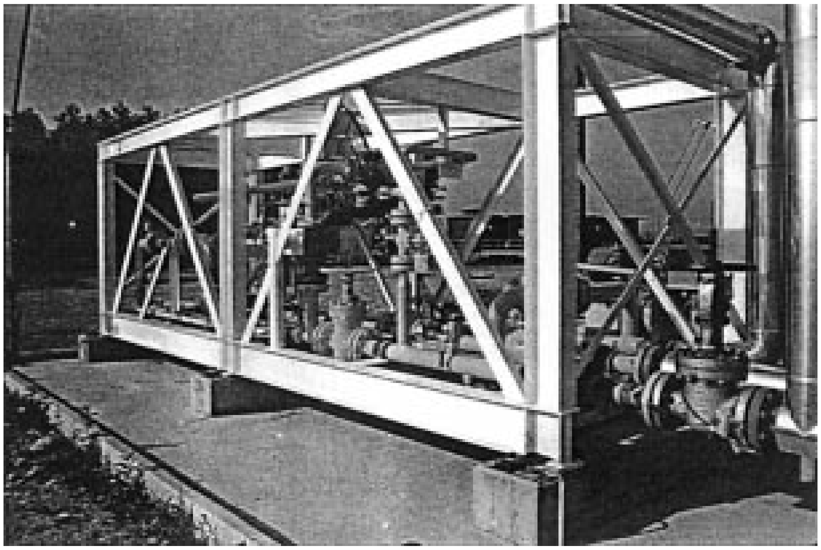


Figure 15. WELLCOM skid in Trecate, Italy.

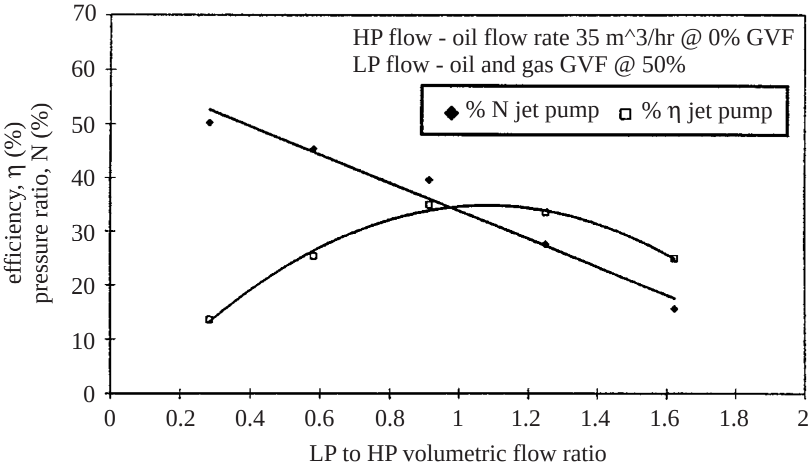
the nomenclature. These results are from the field trials carried out during 1996–97 in Trecate, and match very closely the values predicted and expected of the system.

The key factors which affect the performance of the system are HP/LP flow ratio, HP/LP pressure ratio and the gas volume fraction (GVF) of the low-pressure fluids. Typical performance of the system under different HP/LP flow ratio and GVF values is also shown in figure 17. These curves demonstrate that, as the gas content (GVF) of the LP mixture increases, more energy is needed to compress this gas in the mixture and a lower level of boost is therefore achieved. The value of GVF may reach a level where a derivative of the WELLCOM system (known as the 'Dual WELLCOM' system) will be significantly more efficient. The Dual WELLCOM system, shown in figure 18, enables gas and liquid phases of both HP and LP fluids to be separated and, by using two jet pumps in parallel, HP gas will drive the LP gas and the HP liquid will drive the LP liquid phase.

The impact of allowing the LP wells to operate at a lower pressure, below that of the downstream pipeline and manifold system is shown in figure 13. In this figure, two LP wells with different production characteristics (PI) are shown and, in each case, the shaded area shows the increase in production achieved.

9. The role of compact separators

One of the main reasons for the simplicity, compactness and the reliability of the WELLCOM system is the use of the compact separator shown in figure 19 for gas–liquid separation duties. CALTEC has developed two types of compact separators known as WELLSEP and I-SEP. Both operate on cyclonic principle and generate high 'g' forces at entry to the separator. The generated high 'g' forces cause the separation of dense and light phases (liquid and gas) as the mixture passes through a small separation chamber. The dense phase is accumulated around the outer part of the small separation chamber, and the lighter phase (gas) is collected within the centre core and is captured via a vortex finder. The separated denser phase (oil and water)



$$N = \frac{P_3 - P_2}{P_1 - P_3}$$

$$\eta = \frac{P_2\, Qg_2 \ln \dfrac{P_3}{P_2} + Ql_2\,(P_3 - P_2)}{Ql_1\,(P_1 - P_3)}$$

N : pressure ratio
P_1 : HP pressure at the inlet of the jet pump
P_2 : LP pressure at the inlet of the jet pump
P_3 : discharge pressure at the outlet of the jet pump
η : efficiency of the jet pump with multiphase flow
Ql_1 : volumetric flow rate of liquid phase at HP flow
Ql_2 : volumetric flow rate of liquid phase of LP flow
Qg_2 : volumetric flow rate of LP gas @ P_2 and given temp

Figure 16. Typical WELLCOM performance from field trials.

is collected by a specially designed involute. This type of compact separator has subtle differences compared with conventional hydrocyclones. The separated fluids flow uni-axially through WELLSEP and I-SEP, while conventional hydrocyclones operate with light and dense fluids flowing in the reverse direction. Both WELLSEP and I-SEP have shown to be less sensitive than hydrocyclones to pressure and flow fluctuations, which occur in most upstream production conditions.

WELLSEP and I-SEP are suitable for a variety of other applications within the process system in the oil and gas industry. The potential applications include: gas–liquid separation, knock-out of liquid from produced gas, sand separation and oil–water separation. For gas–liquid separation duties WELLSEP is suitable for gas volume fraction (GVF) values below 80%, and I-SEP works well at GVF values beyond 80% and up to 99%. These separators are very compact and their size is only a small fraction of the conventional gravity separators. WELLSEP has already been tested

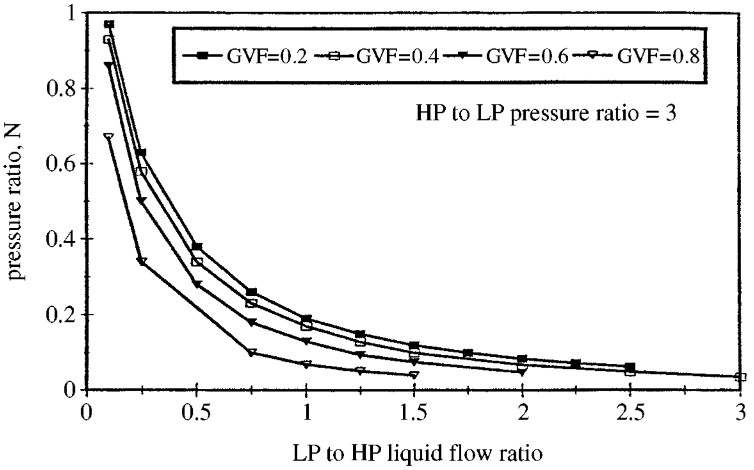


Figure 17. General performance of WELLCOM system.

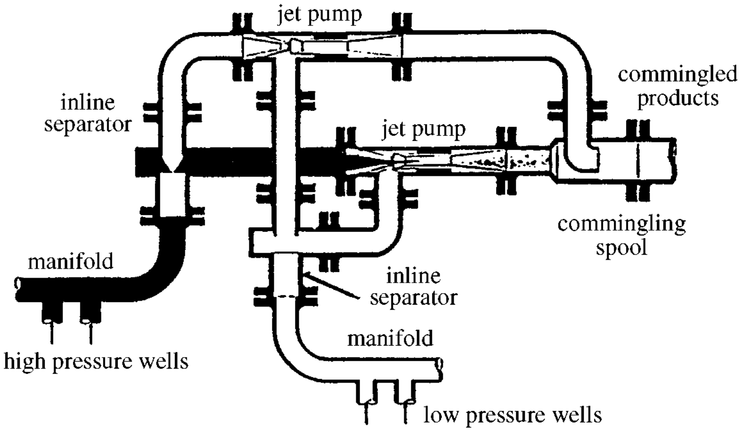


Figure 18. Dual WELLCOM configuration.

in Trecate field as described earlier. A model of I-SEP has already been successfully tested for downhole gas–liquid separation duties. In addition to compactness, these separators have the benefit of having no moving parts and requiring no active pressure or level control. The use of compact separators is becoming more frequent in the industry because of their inherent benefits. More demonstration and field trials are, however, needed in order to establish their full range of applications and to gain the confidence which the industry needs for such new products.

10. Modelling

Equipment, such as the WELLCOM system, requires an accurate model for prediction of its performance under different operating conditions and hydrocarbon products. In addition, an optimum design of the system is required for each field application. A comprehensive model has been developed which offers both functions. The performance of the jet pump, which is the key component of the system, has

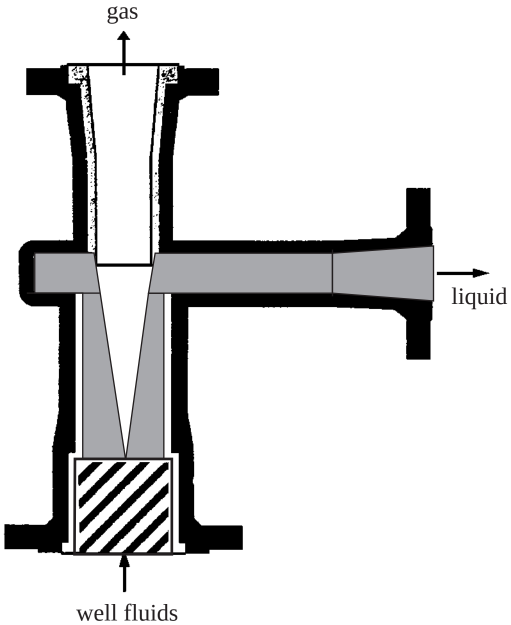


Figure 19. General configuration of WELLSEP.

been modelled by computing the mass, momentum and energy balance at five distinct points within the jet pump, and taking into account the compressibility of the mixture. Appropriate loss factors have also been incorporated for multiphase flow through the system.

The software has been validated using data obtained from the extensive laboratory tests and field data. In all cases the jet pump has performed better by 0–2.5% in comparison with the software predictions. This level of accuracy is quite acceptable in the industry, knowing that there is often a similar or higher level of inaccuracies in the data supplied or obtained from the instrumentation, which may monitor the performance of the system.

11. Applications of the WELLCOM system

The system can be applied whenever products from the producing wells are at different pressures. As shown in figure 17 and described in § 7, the flow ratio and pressure ratios of HP/LP fluids should be enough to gain sufficient boost from LP wells and to provide the minimum delivery pressure which is required by the pipeline transportation system. The products may be supplied from either the same well with a dual completion where the long and short strings within the wellbore produce from different zones. Alternatively, HP or LP flow may be supplied from satellite wells from a different field, or a separate part of the reservoir.

In some applications newly drilled wells with higher production pressures may enable to extend the life of low-pressure wells and increase recovery. In applications where no high-pressure wells exist, the motive flow can be supplied via a single phase booster pump. The motive fluid can be oil or water in this case. Figures 20 and 21 show the examples of this application which can be onshore, offshore (topsides) or

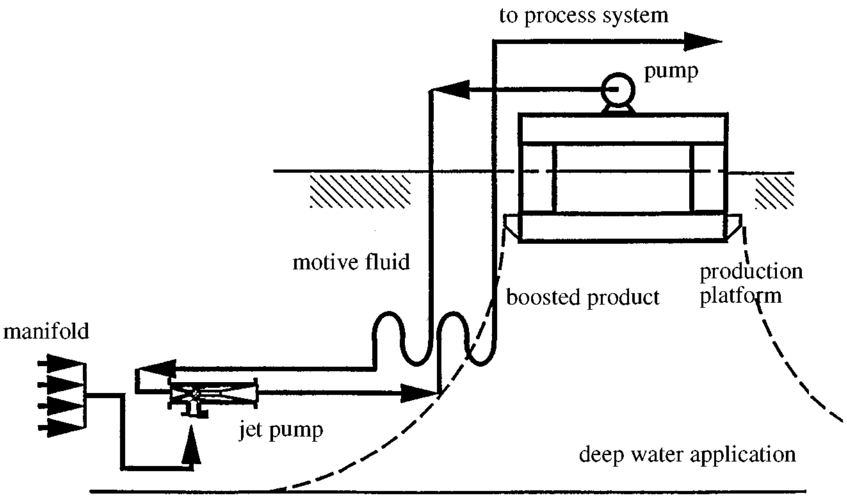


Figure 20. Application of WELLCOM boost.

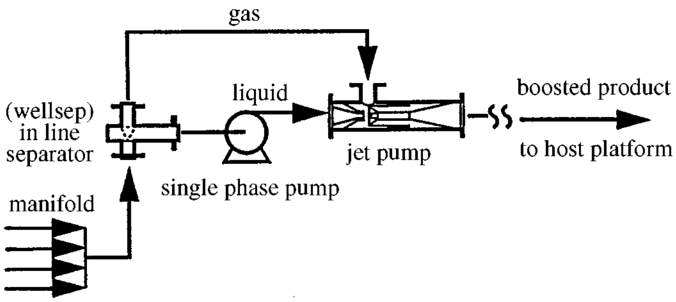


Figure 21. WELLCOM boost application.

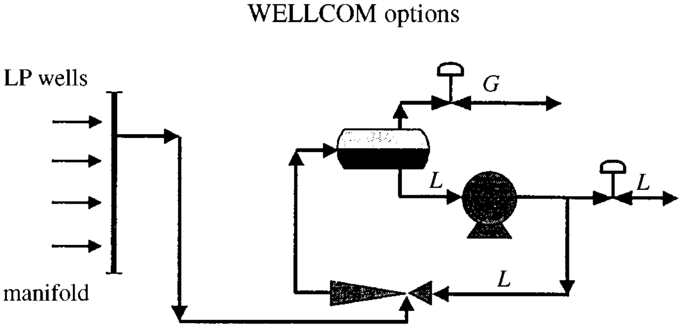


Figure 22. Multiphase jet pump with a booster pump.

subsea. In the case of the subsea applications, the jet pump could be the only subsea component, and the booster pump, which is the part of the system that may require maintenance, is located topsides where it is easily accessible.

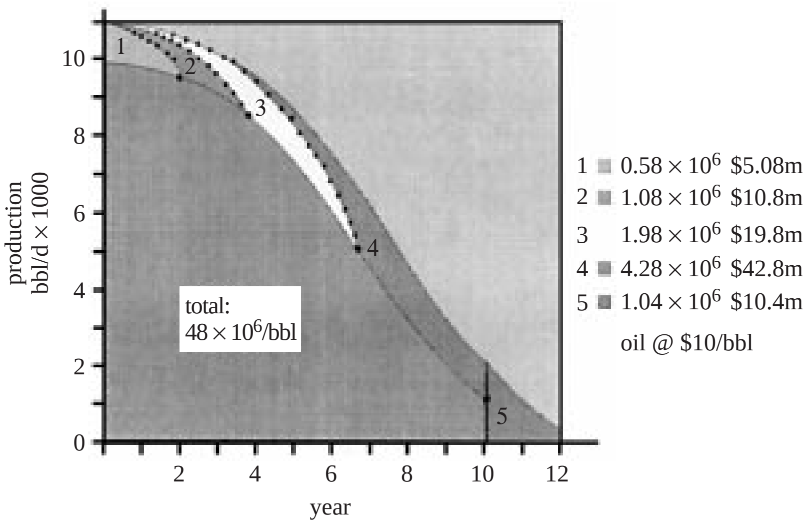


Figure 23. WELLCOM economics—oil production.

(*a*) *WELLCOM Boost*

The system can also be incorporated into an existing process train as shown in figure 22. In this example, the energy from the high-pressure oil downstream of a pump is used to boost the pressure of the produced LP fluids. In this case the back pressure on LP wells is reduced and their production is increased. In a similar case the jet pump can be used to boost the pressure of the LP gas without the need for a costly compressor or a multiphase pump. The systems which use a single phase booster pump are called 'WELLCOM Boost' because of the presence of a booster pump for supplying the motive flow.

These are some of the examples of the WELLCOM system application where either energy from an existing high-pressure source is used to boost production or the high-pressure motive fluid is generated by a single phase pump which is simpler and of a lower cost compared with options which involve the use of compressors or multiphase pumps. In most applications, it is advisable to use a liquid phase, in preference to high-pressure gas as the motive flow, because of the significant difference between the mass of the liquid and gas phases.

12. Benefits of the WELLCOM system

The main benefit of the system is its ability to use the energy, which is usually wasted through choke valves, to boost production from low-pressure wells. The main problem which low-pressure wells or marginal fields face is that, because of their low production rate and the limited total recovery, using boosting systems that are of high capital and operation cost becomes uneconomical. As a result, such fields may be abandoned or their production may be severely restricted. The WELLCOM system, because of its low capital cost, becomes therefore a cost-effective solution to boost production and recovery from such low producers.

The system has also other benefits, which include the following:

it increases total recovery from the field;

Table 1. *WELLCOM economics—gas production*

increase in production	gas price
(1) 0.75×10^6 scf per day	£1/1000 scf
(2) 2×10^6 scf per day	
(3) 15×10^6 scf per day	
payback period	
(1) 40–50 days	capital £30k–£37.5k
(2) 20–25 days	capital £40k–£50k
(3) 6–8 days	capital £80k–£120k

low capital cost;

highly reliable, because of the simplicity of components;

compact, with no moving parts;

in some applications, it eliminates the need for other costly boosting systems such as compressors or multiphase pumps;

does not require active control;

because of low capital cost, its application could even be justified for a short period as the payback period is short, often a matter of a few weeks or months;

the system can be applied onshore, offshore, topsides and subsea;

in some applications, it prevents flaring of LP gas with added environmental benefits.

13. Economics

The economic benefit of the WELLCOM system is the added revenue it generates by increasing production and the total recovery from fields. The level of benefit depends on how long the HP fluids are available or the system can be used. Table 1 and figure 23 show some typical examples, which take into account different levels of boost in production and the duration of the system deployment.

In all examples, it is shown that the payback period for the recovery of the capital is short and is often a matter of a few weeks or months. This is also confirmed by the actual recent field applications such as those used by AGIP for their Villa Fortuna wells in Northern Italy and their other onshore and offshore applications.

There are also many field examples in gas production applications in the North Sea (Sarshar *et al*. 1997) and Italy (Villa *et al*. 1997), where the payback period for the system has been as low as three to four weeks. These indicate and confirm that, even if the system can be used over a short period of a few months or a year, it still makes good economic sense to use it and defer other costly options to a later date when the high-pressure source is no longer available. Other economic benefits apply to cases where flaring of LP gas is prevented, or the use of a separate low-pressure line and low-pressure process system is avoided, by increasing the pressure of the produced fluids and using the existing transportation system.

In applications where the total recovery from the field is improved, this adds to the value of the asset and helps in improving the economics of many marginal fields which are near the end of their production life.

14. Commercialization

New equipment, which is developed and fully tested, requires further major steps to achieve the full status of commercialization ready for field application. The key issues involved are

fabrication details;

material selection for various applications;

meeting the requirements of international codes, such as ASME, API, BS, Dnv stoomwezen (Dutch), and obtaining certification for material, welding, workmanship, pressure testing, etc.

All the above issues have been addressed extensively in collaboration with a number of fabricators who are well experienced in manufacturing similar equipment for the oil and gas industry. The few units already manufactured have also provided a good learning experience, and the work has led to further enhancement of the system to ease manufacturing and the change-out of some of the components, such as the nozzle of the jet pump, during its service life.

The system is therefore fully ready for supply to the industry with a choice of a few manufacturers who collaborate with CALTEC to provide the full service, which covers design, manufacture, supply, commissioning and the service during the operational life of the system.

15. Conclusions

The WELLCOM system is a cost-effective way to boost production and total recovery from many low-pressure fields.

The simplicity, reliability and low capital cost of the system make it ideal for the marginal fields which cannot afford the high capital and operational costs of alternative boosting systems.

The payback period for most applications is short, a matter of a few weeks or months.

The system has already enjoyed extensive field trials, and a comprehensive computer model has been developed and validated for the design and prediction of its performance.

The system is now ready for its field applications with a full service covering design, manufacture, certification and commissioning offered by CALTEC in collaboration with a number of reputable fabricators.

The industry is undergoing major changes in organization and policies in order to cut costs and to maximize efficiencies in response to the low price of oil and the financial constraints imposed by many marginal fields. Further steps are also taken to involve major contractors to form alliances with the producing oil and gas companies. These steps have the habit of resulting in cutting costs on research and development. These cuts are made at the time when the industry needs new cost-effective systems or techniques which can improve production and recovery from fields, or to reduce capital and operational costs.

There are many small to medium size companies who have excellent ideas, concepts or products which, when fully developed and tested, will benefit the oil and gas producers extensively. Starving the small companies of funds that are needed to develop their products will delay the availability of such products that are needed now but will take at least three to five years to develop. The author's plea to the industry and the organizations which provide funds for the development of new products is to maintain their support at a healthy level so that, not only the new techniques and equipment become available, but their development is speeded up further for the benefit of the producers and all concerned. This, in the long run, will be the best way to improve the profitability and the viability of the marginal fields which form a major part of the future source of oil and gas supply.

Full development and commercialization of novel systems, such as WELLCOM, is a time-consuming and costly exercise, which requires a dedicated team of engineers and sufficient funds to achieve success. CALTEC thanks the following organizations for their encouragement and financial support during the various phases of WELLCOM development: AGIP Spa, Amerada Hess (UK) Ltd, The European Commission (Thermie programme), JP Kenny Caledonia Ltd (Wood Group Engineering), Marathon Oil UK Ltd, Mobil North Sea Ltd, Oil and Gas Supplies Office (OSO, presently named IEP), Sarawak Shell Berhad (SSB), Score Europe Ltd.

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