Baker Hughes is a world-leading technological corporate group in the oilfield service industry. Based in Houston, Texas, the company has a presence in over 60 countries and employs around 27,000 people of nearly 100 nationalities. With seven divisions linked to its product lines – Baker Hughes INTEQ, Baker Oil Tool, Hughes Christensen, Baker Atlas, Baker Petrolite, Centrilift, and Baker Hughes Drilling Fluids – Baker Hughes carries out research and development and works for all mineral oil and natural gas producing organizations around the globe.

Over 850 employees are based at the German branch office in Celle. Eighty percent of them work for the INTEQ division, where drilling systems are developed and marketed internationally. Our sales region incorporates central and eastern Europe, Russia and central Asia. Baker Hughes also offers highly specialized services for drilling rigs (particularly for directional drilling). Almost 30 percent of our staff members in Celle are engineers.
Baker Hughes around the world and in Celle

Baker Hughes is a world-leading technological corporate group in the oilfield service industry. Based in Houston, Texas, the company has a presence in over 70 countries and employs around 36,000 people of nearly 100 nationalities. With seven divisions linked to its product lines – Baker Hughes INTEQ, Baker Oil Tool, Hughes Christensen, Baker Atlas, Baker Petrolite, Centrilift, and Baker Hughes Drilling Fluids – Baker Hughes carries out research and development and works for all mineral oil and natural gas producing organizations around the globe.

Over 1,200 employees are based at the German branch office in Celle. Eighty percent of those work for the INTEQ division, where drilling systems are developed and drilling systems and diamond bits are produced and marketed internationally. Our sales region incorporates central and eastern Europe, Russia and central Asia. Baker Hughes also offers highly specialized services for drilling rigs (particularly for directional drilling). Almost 30 percent of our staff members in Celle are engineers.
THE FASCINATING WORLD OF DRILLING TECHNOLOGY

Products from Baker Hughes and their Functions
Principles of Drilling Technology 15

2.1 Where is Oil to be found? 16
2.2 What does a Rig look like? 18
2.3 What is the structure of a Drill String? 21
   The Bit 21
   Drill Collars 23
   Drillpipes 24
   Shock-Absorbers, Drill Jars 24
   Stabilizers 25

2.4 Well Path 26
   Vertical Drilling 26
   Directional Drilling 28

What does INTEQ manufacture? 31

3.1 Drilling Systems 32
   Drilling Motor (Ultra, X-treme) 32
   Rotary Steering System (AutoTrak) 35
   Vertical Drilling System (VertiTrak) 39
   Coiled Tubing Assembly (CoilTrak) 42

3.2 Evaluation Systems 45
   Where are we going? (OnTrak) 45
   What do we know about the Rock drilled out? 49
      Sand or Clay? (Gamma) 50
      How large are the Pores? (Nuclear) 51
      Is Oil, Gas or Water in the Pores? (Resistivity) 56
   Can the Oil or Gas found be delivered? (MagTrak) 57
   How good will the Yield from the deposit be? (TesTrak) 59
   How reliably and well do we drill? (CoPilot) 61
   Can the data flow from downhole to surface be optimized? 64

3.3 Application and Planning Software 68

And Finally 73
Introduction
INTRODUCTION

“Hello!”

You probably have never thought about it: When you are sitting comfortably and are not under too much stress your heart beats about 60 times a minute. In an hour your heart beats approximately 3,600 times a minute, therefore in the course of a working day (excluding your lunch break) it means about 27,000 times!

That’s quite a lot isn’t it! I hope you are still with me so far. But why are we thinking about heartbeats and the number 27,000? Now, by chance, the Baker Hughes Corporation has approximately 27,000 employees worldwide! Thus every pulse in the course of a long working day corresponds to a colleague within the corporation. Would you have known that?

Our employees come from a total of almost 100 different nationalities. Our branches, i.e. offices, workshops, stores and fabrication plants, are located in more than 70 countries all round the globe. The headquarters of our Corporation is located in Houston, in the US state of Texas. Most of the important decisions are made there, so it is often necessary to travel to the USA for business purposes.

The Baker Hughes Corporation is not altogether easy to comprehend when taken as a whole. It is therefore divided into several handier “divisions”, which offer a wide range of services to the oil and gas industry. A detailed description of the work of all the divisions would soon fill up a whole book. Here in this introduction, we only intend to give you a brief summary of our most important spheres of activity:

Wherever a hole is to be drilled, rock has to be crushed. Hughes Christensen manufactures the bits required for this.

A bit has to turn, otherwise it will not drill. The drives for the bits are supplied by the INTEQ division, to which the company MCT (Motor & Coring Technology), also still sometimes wrongly called the “rubber works” or “Elastosystem”, belongs. The INTEQ division also provides evaluation tools that survey and monitors the well whilst it is being drilled. This is known as MWD (Measurement While Drilling). The borehole has to be cleaned constantly and the bits cooled whilst they are drilling. Drilling fluid is used for this purpose. Although, this is supplied by the Baker Hughes Drilling Fluids division, many special chemicals and additives are supplied by Petrolite.

After drilling, the hole is thoroughly surveyed again with the evaluation systems from Baker Atlas. Now we really know, quite precisely, what its path is, what it is like, and where the coveted oil or gas is to be found.

Now the borehole is ready, and is stabilized for the life of the well by Baker Oil Tools using a “completion” method that will prevent the borehole from collapsing. Baker Oil Tools is also a specialist in “fishing tools”, with which any equipment and items which may be lost down in the hole can be brought back to the surface. If the oil is no longer forced up to the surface on its own by the pressure of the reservoir, delivery can be brought back into swing by using underground pumps from Centrilift.

Granted. When considered superficially, many of these services will seem relatively unspectacular to a layperson. This is probably also why there is so little general understandable literature on the subject. However, the deeper you stick your nose into the details of the different technical areas, the more fascinating secrets you discover and the more you are amazed in the end by the technical wonder of the products that have been developed.

Each division of the corporation has earned the right to have its products not only explained to experts but also sometimes to laypeople interested in the engineering of them. Detailed product material can be found everywhere in plentiful quantities. Now, however, a start must be made somewhere, therefore this book deals especially with the products of the INTEQ Division.
We, that is, as of now, Baker Hughes INTEQ, are a large service company which, with approx. 5,500 employees and branches in more than 50 countries, is represented almost everywhere worldwide and would like to be THE drilling company of choice in the oil and natural gas industry.

We develop, construct, and sell equipment which is used for producing wells. These are in most cases several kilometers deep, with diameters usually between 6 and 12 \( \frac{\text{inches}}{} \). These wells are often of a curved design, whereby the end of the well runs horizontally through the oil/gas deposit. This area of our activities is described by the term “Drilling Systems”.

Modern wells must be positioned very precisely so that optimum production is achieved. This is only possible by using elaborate evaluation systems which are taken down the hole, together with the “Drilling Systems”. These pieces of equipment measure the borehole during drilling, and tell us in this way, exactly WHERE we are drilling. They also give us information on WHAT we are drilling (what rock is on the bit and whether there is oil or gas in it), and also, HOW we are drilling (whether the drilling parameters used are set so that they are the best possible). We also develop and construct these measuring instruments (we call them “Evaluation Systems”) and use them all over the world.

Our branch in Celle started life in 1957 as a small fabrication workshop making coring bits and, a little later, diamond bits. In the 70s, the product range was extended to cover other components of the drill string. First of all we developed shock-absorbers, which were to protect the drill string from damaging vibrations, and drill jars which could tear loose again any drilling equipment which had become stuck in the borehole during the drilling process.

The first “Navi-Drill” also appeared in the range in the 70s, these are drilling motors which supply our bits with extra drive energy, directed at the bottom of the drill string and thus led to increased drilling speed.

The 80s produced the major breakthrough of “directional drilling technology”; the targeted drilling of curves using kick-off drilling motors in conjunction with “MWD-systems”. In this way, reservoirs (oil/gas deposits), where access had previously been difficult, became reachable.

The 90s were characterized by “intelligent drilling equipment” which could find their own way to or through the reservoir to an increasing extent. The best known representatives of this type are “VertiTrak” and “AutoTrak”.

All of these (and many other) products were developed and constructed in Celle, and almost every employee will use the current product designations on a daily basis.

But with hand on heart, who really knows how all these drilling tools work and what they are used for? Many of the yellow/blue, rust brown or silver-colored “pipes” on our shelves reveal themselves as real technical miracles when they are investigated more closely, but far from all the employees know about this!

The situation is no better as regards our knowledge of the Evaluation Systems Department since this product was primarily developed in Houston in the past and we are therefore less well acquainted with it than with our own drilling tools. The majority of our colleagues in Celle have at best a very vague understanding of how the complicated evaluation systems in a modern drill string work and what they measure.

The present book is intended to help in closing these gaps in your knowledge. Of course it cannot provide detailed knowledge in a hurry, but it is intended to give our INTEQ-employees, and all those interested, an overview of the products which our company manufactures, explain how they work, how they are used, and for what they are used. This book is particu-
larly aimed at those readers who have no, or a very
unclear, idea about the drilling and evaluation oper-
amons. Not only is the mode of operation of our products
complex, but the extreme conditions in which they are
used also have to be taken into consideration. The drill-
ing process often has to handle temperatures, deep
down in the ground, which we use at home in the oven
to cook a pizza. In addition to this, static pressures of
500 to 1,000 bar are present (automobile tires are only
pumped up to a pressure of 2 bar), along with violent
impacts and vibrations, and an aggressive environ-
ment in the form of drilling fluid, sharp-edged drilling
debris, and possibly other chemicals.

It is quite obvious that our drilling tools cannot
survive for "a lifetime" in these conditions. No, in our
industry we are already very satisfied if tools can sur-
vive for 150 hours or even a little longer without prob-
lems and breakdowns. After each use, the equipment
is brought out of the hole, sent back to one of our
many workshops worldwide, dismantled into its small-
est individual components for inspection, carefully
inspected and repaired if necessary, and then reas-
sembled so that it can be used again.

Of course, this amounts to an enormous expense.
But it means that our customers can always rely on
receiving the most high-performance and reliable
drilling systems in the world.

So now, follow our colleague in his work clothes
around the "Baker Hughes INTEQ Drilling Technology
Exhibition". He will guide you and explain to you what
a rig looks like, what we mean by the term "directional
drilling", show you a selection of drilling and evalu-
ation systems which have been developed and con-
structed within our corporation, explain their mode
of operation in such a way that a layperson can under-
stand it, and at the same time, provide basic informa-
tion about the geology of oil/gas
and important stages in the devel-
opment of drilling technology.

We hope you enjoy this
excursion!
Before we consider how holes are drilled for delivering oil or gas, we need to think about where oil and gas can be found.

Oil and natural gas are produced in a long-winded and complex process from organic material, i.e. from plants and plankton.

Of course, organic material is normally decomposed by bacteria and becomes earth; you can see this in your compost heap at home. However, if the organic material collects at locations where there is no oxygen (for example in very deep parts of the seas, or if the items of material are layered so quickly one on top of the other that the lower layers cannot be decomposed fast enough), then the decomposition process is disrupted or even prevented. In this way, the organic material is retained and is available for the continued oil and gas creation process.

It is well known that the surface of the earth is not rigid, but is in constant movement. The continents move unhurriedly over the globe, no doubt you have read or heard about this. Although this movement takes place slowly, it is unstoppable and causes earthquakes, for example where two continental blocks collide. Strata of the earth push over each other all over the place, formerly flat regions are folded together to form mountains, or other areas sink down into the depths of the earth where higher temperatures are present.

If the organic material, from which oxygen had been excluded, is heated to temperatures between about 60 and 150°C (because it has sunk down into deeper rock strata), the conversion to oil and natural gas gradually begins. Whether more oil or natural gas forms depends on the exact composition of the biomass and the temperatures.

Groundwater is usually present in the pores and cavities of the earth. The freshly formed oil and gas are lighter than water, and therefore attempt to climb upwards through the fine cracks in the rock in the direction of the earth’s surface. In most cases, this succeeds and the oil or gas finally escapes unnoticed on to the surface.

However, occasionally, the rising oil or gas will also strike natural obstacles, for example, impenetrable layers of clay. If these are shaped like a pan lid, relatively large deposits can collect underneath them through the course of time. The lightweight gas is to be found in the upper pores and cracks of the rock, the heavier oil will be underneath it, and underneath that, the still somewhat heavier groundwater.

So the oil or gas is not to be found in the form of underground seas, as most people imagine, but rather it sits in the fine pores of the rock. Many famous buildings are made of sandstone, like the Semper Opera House in Dresden for example. This is how you must imagine the rock of the deposit, in the pores of which the raw materials are located.

Anyone looking for an oil or gas deposit must therefore ask themselves the following questions:

- Where in the world are there natural obstacles to hydrocarbons which may be rising (for example clay layers)?
- Is porous material present under these impenetrable layers, in which oil or gas could have collected?
- Are the pores large enough to form a worthwhile deposit?
- Is the deposit really oil or gas?
- Are the pores connected together so that oil or gas can flow through the rock to our well?

Now, we can hopefully obtain answers to the first two questions from the geologists. Using their measurements, a decision is made as to whether a rig should be set up and a well “sunk”. We will have to answer the subsequent questions in the course of the drilling process, in that we drill into the potential deposit and take...
samples from it. But we will come to this in greater detail in the chapters which follow.

First of all we need to talk a little bit about the general principles of drilling technology.

If the geologists’ measurements indicate possible gas or oil in the ground, a rig is set up, which can drill into the reservoir, and investigate it in greater detail.

Even if we like to use pictures of large rigs and floating drilling platforms from the colored advertisements in technical journals as decoration: Baker Hughes INTEQ does not possess any rigs at all, nor does it manufacture them either! Nonetheless, the general structure of a drilling system will be described briefly here to enable you to have a general understanding of the drilling process.

In principle a rig is a crane, on the hook of which the drill string is suspended. The drill string consists of “drillpipes”, these are pipes with a threaded connection on both ends. A drillpipe is usually 10 meters long (the Americans prefer to call this length “30 feet”). Depending on the height of the rig, before drilling starts, 2 or 3 drillpipes respectively are screwed together to form a “stand”. The 30 meter long stands are sorted into a rack, and this allows for the work to go more quickly later when drilling actually starts. Whenever a stand has been drilled down, the next stand is screwed on to the drill string. So this becomes longer and longer until the borehole reaches its final length (the technical expert refers to “target depth” or “TD”). Here in Germany, boreholes 4 to 6 kilometers deep are usual, in other countries they can be a few kilometers longer or shorter.

Of course, the drill string must be rotated; otherwise the bit screwed on at the bottom does not drill. Depending on the design of the system, the rotation (“string”) drive either takes the form of a “rotary table”, located under the working platform, or a “top drive”, suspended in the crane hook.

The drilling debris (or “cuttings”) which the bit produces, must constantly be transported out of the hole, otherwise it becomes blocked. Therefore, a drilling fluid (usually a watery sludge) is pumped through the drill string down into the hole. The drilling fluid flushes the cuttings away from the bit and discharges them into the ring-shaped space between the drill string and the borehole wall (the “annulus”), and up to the surface. Above ground the fluid flows over screen shakers on which the debris is separated out and is then routed to settling tanks. The fluid, cleared of the cuttings, is then returned to the hole for a new cycle.

A great deal of energy has to be expended to pump relatively large quantities of viscous fluid through a long, narrow borehole and back to the surface (it often has to be several thousand liters per...
minute). Therefore, the fluid pumps on the rig, and the associated diesel drive units, tend to be more like a small truck than a garden pump. No doubt you will have seen a "Blowout" at some time on television; that is the most serious possible accident which can happen. This takes place when the oil or gas shoots up to the sky like a giant, possibly even burning, fountain. Of course, something like this should not happen in “real life”. Therefore, there is a very well thought-out system of safety valves under the working platform, the "Blowout Preventer Stack". This "stack" can be used to reliably control the well, and, in an emergency, shut it off if necessary.

In principle, that is all that needs to be said about rigs. Of course, most drilling platforms also have a residential unit and a helicopter landing pad, some drilling platforms float, others stand on long legs on the sea bed, but in the end, the general structure is still always the same.

In principle, that is all that needs to be said about rigs. Of course, most drilling platforms also have a residential unit and a helicopter landing pad, some drilling platforms float, others stand on long legs on the sea bed, but in the end, the general structure is still always the same.

The bit is right at the bottom of the drill string. It breaks up the rock and converts it to cuttings which are flushed out to the surface with the drilling fluid. Baker Hughes INTEQ itself does not produce bits, but our sister company Hughes Christensen does. Hughes Christensen is also located on our work site and was the nucleus of our Celle Works almost 45 years ago. A bit has an unbelievably hard life. The drill string presses down on the bit from above with a loading of several tons, under it there is the rock, which can often be extremely hard. Depending on the type of bit and the type of drive, the bit can turn between approx. 100 to 1,000 revolutions per minute, and therefore often rotates several million times in the course of its life. It is not unusual for the bit to drill a distance of several kilometers in one go, of course, it should remain sharp as long as possible, drill quickly, and not wear during this, and if it is up to the customer, should also be very reasonably priced.

Of course, it is quite obvious that not all these requests can be fulfilled at the same time but rather, as everywhere else in life, it is necessary to make compromises.

Bits can be divided into two rough main groups, rollercone and diamond bits.

As the name already suggests, roller cone bits have three rollers.
fitted with teeth which crush the stone and mill it into debris. They are relatively cheap to purchase but do not have an unlimited long life because they contain ball bearings and many moving parts. After one to two days drilling time, in a difficult formation, and with a high bit loading, a bit of this kind is at the end of its life despite its precise and robust design. Care must be taken that the rollers do not gradually become loose, or in an extreme case, actually fall off. In fact, if there is scrap in the hole it is not possible to continue drilling. Therefore, the missing roller cone must be recovered, using time-consuming fishing procedures, before the next bit can be fitted. This costs the drilling contractor a lot of time and money and is therefore extremely undesirable.

Of course, it is possible to limit the life of a roller-cone bit to avoid such occurrences by simply exchanging it early enough, but this is problematic because it means that the string has to be removed and reinstalled more often than necessary. This process takes a great deal of time and is therefore expensive.

The use of diamond bits, which cut the rock as if on a lathe, offers a welcome alternative to the rollercone bit. Diamond bits are equipped with several ribs, on the front edges of which, cutting elements made of diamonds are fitted. As these bits have no moving parts nothing can get lost in the hole, even if used for a long time. That is a clear advantage over rollercone bits. However, the diamonds and manufacture using time-consuming manual work are relatively expensive, so that a “standard” diamond bit costs easily as much as a better quality medium-sized automobile.

In the final analysis, which bit is used for which project is dependent, first and foremost, on the rock to be drilled (the “formation”), and then the conditions of use in the drilling operation. Each operation must be decided individually. The specialists at our sister company Hughes Christensen are available at any time to give help and advice in selecting the best bit and ensuring that the most advantageous compromise of procurement cost and drilling output is found for the customer.

A drill string, with which a hole perhaps six kilometers deep and less than 30 cm in diameter, is to be drilled has a ratio of diameter to length approximately equivalent to a relatively long hair. Even though the individual drillpipes are made of iron and apparently seem rigid, the entire drill string is an extremely flexible structure when considered as a whole.

The bit, right at the bottom of the string, must be pressed forcefully into the rock so that it drills quickly. You, therefore, might think of pressing the string into the hole from the top of the rig to increase the drilling speed. However, in many cases this will not work because the string bends under pressure or in some cases even buckles. If this happens the pipe can become stuck in the hole and, ultimately, can no longer be pushed forwards at all.

It works considerably better if the bit loading is generated by a few dozen “drill collars” at the lower end of the drill string. Drill collars are particularly thick-
walled and therefore heavy drill-pipes. Part of the weight of these drill collars presses the bit into the rock, the remaining weight ensures that the drillpipe above the drill collars is under tension up to the surface and therefore cannot buckle.

The drill string between the drill collars and the crane hook on the surface consists for the most part of simple pipes which have threaded joints at each end so that they can be screwed together (see chapter What does a drilling rig look like?). These pipes are referred to as drill-pipes. It is easy to imagine that when drilling hard layers of rock, with bit loads amounting to several tons, and high rotary speeds for the drill string, that this procedure can be fairly rough. All of this is normal in principle though, and our down-hole tools are designed for such conditions.

Nonetheless, shock-absorbers are often installed in the strings to absorb impacts and vibrations or at least dampen them so that the drill string lasts longer and is protected from unnecessary damage. These shock-absorbers usually involve strong packages of springs but sometimes also hydraulic cylinders similar to the shock-absorbers used in an automobile.

Occasionally, the situation arises that rubble (large pieces of formation) becomes detached from the borehole wall, and then becomes wedged between the drill string and the solid rock in such a way that the drill string becomes stuck in the hole and cannot be moved. Of course, this is extremely awkward, because in the worst possible case it is impossible to get the string free again so that the well has to be abandoned and started again at a different position. To minimize the risk of becoming stuck, usually one or more jars are installed in the string. Jars are pieces of equipment which can release heavy blows underground if necessary, i.e. close to the problem zone, which are intended to tear the drill string free again.

INTEQ has withdrawn from the drill jars and shock-absorbers side of the business; we no longer manufacture these products ourselves. However, about 50 years ago, alongside the manufacture of bits, these products formed a second important part of the company in Celle, which was still very young at that time.

The drill string has a smaller diameter than the borehole because the flushing liquid (the drilling mud) which is pumped through the string to the bit has to rise to the surface again outside the drill string.

Stabilizers are integrated at a few points in the drill string to ensure the drill string has defined guidance in the borehole. A stabilizer comprises of a short pieces of pipe which has several guide pads, the stabilizer blades, around its circumference, which hold the drill string firmly in the centre of the borehole. You will no doubt have often seen stabilizers of this type if you have walked past the shelves in the yard at the works site.
So. We have now learnt what a drill string looks like. But
what does a well look like? Is it true that we sometimes
drill curves? And if so, why do we do that?

The technique of rotary drilling, i.e. drilling with a
rotating drill string is in itself not very old. It did not
become popular until the beginning of the last century.
At that time the rotary drill string only consisted in
principle of the bit and drilling assembly above it
comprising the drill collars and the drillpipes which
were rotated from on the surface. The drilling mud
is pumped downwards through the drillpipes to the
bottom of the hole. Once there it cools the bit and
carries the cuttings out of the borehole back to the
surface through the annular space between the bore-
hole wall and the drill pipes.

The path of a well drilled using the traditional rotary
principle was usually designed to be vertical. In fact, a
genuinely vertical well only succeeded in the rarest of
cases. The path of the well tended to be deflected by
the position of the rock strata in respect of each other,
their angle of inclination and the varying hardness of
the rock in the strata. It was possible to influence the
direction of the well slightly via skilled arrangement of
the stabilizers within the drilling assembly. So-called
building assemblies are used to increase the deflection
of the well from the vertical and drop assemblies to
reduce the inclination.

If a well produced a positive result, additional wells
were sunk in the area to maximize the delivery of the
field. Photographs from the period around 1900, for
example, including those of oilfields near Celle at
Wietze, are a reminder of what was state of the art at
that time. The rigs stood side by side as far as the eye
could see.

There was already a suspicion: drilling straight
down into a reservoir containing oil or gas somehow
did not represent the most effective method of open-
ing it up. It is true that normal reservoirs are often
widely spread out in the horizontal plane (length and
width) but at the same time only have a shallow thick-
ness. You should not imagine oil and gas reservoirs to
be like underground seas. No, the hydrocarbons (oil
and gas molecules are consisting of carbon and hydro-
gen atoms) are located in the fine pores of the rock and
cannot flow freely in any desired direction. A vertical
bore, which runs from top to bottom through the thin
reservoir therefore only reaches a relatively small
amount of oil or gas.

Usually better results are achieved with a “direc-
tional” borehole, as is described in the next chapter.
Our company, INTEQ, has specialized in drilling “curved” boreholes, on purpose and aiming precisely at where we suspect the largest pores filled with the best hydrocarbons are to be found. This method, i.e., controlled drilling of curves and straight sections as required is called “directional drilling.” We preferably drill downwards using the shortest route to the deposit, then horizontally for miles through it. The surface of a horizontal borehole in the reservoir is enormous in comparison with a vertical borehole and correspondingly more oil or gas can be delivered.

Directional drilling also makes it possible to drill many holes in different directions and to open up a complete field in this way from one drilling platform without having to move the expensive platform. A further application of the directional drilling technique arises, for example, if a reservoir is under a town or a nature conservation area in which it is not possible to set up a rig. In this case the rig is erected a few kilometers away and then drilling runs underground to the target. The advantages of directional drilling are obvious. But of course it is not possible to produce a directional borehole with a simple drill string with the bit screwed to the bottom, but rather extremely specialized directional drilling equipment and appropriate evaluation systems must be used. The development and operation of equipment of this type is our specialty, no other company is close to being able to show us, INTEQ, anything about this subject.

Did you actually know that most of our products are so complicated that in most cases we do not sell them at all but always only rent them out and send the specialists out with the equipment, thus guaranteeing technically correct handling? We talk about “directional drillers” and “MWD-operators, who have recently also become known as “FSE” (Field Service Engineers) for short. Without FSE on board, directional drilling does not even start.
What does INTEQ manufacture?
Now we have learnt so much about what a drill string looks like, it is finally time to find out what concrete contributions our company makes to the success of the borehole.

We already said in the introduction that our products can be divided roughly into drilling systems and evaluation systems. The next chapters will introduce you to the most important product lines, explain how they work, and what they are used for.

To put in general terms: the faster the bit rotates at the bottom of the hole (and the more firmly it is pressed into the rock) the faster it drills. Therefore the faster you turn the drill string the faster you drill, or is that not the case?

Now… unfortunately it is not quite so simple. The drill string is of course put under greater strain by the higher speeds and wears correspondingly more quickly. A downhole motor solves the problem, it drives the bit directly on the spot at a high speed and with high torque whilst the drill string only rotates slowly or in other cases does not rotate at all.

INTEQ has been developing and selling downhole motors since the 70s and to date our NaviDrills (as we call them) have always remained a “best in class” product.

Of course a downhole motor has nothing in common with a combustion engine, such as we find in an automobile. Rather, it functions like a “reverse pump”. A pump uses the drive energy to set a liquid in motion. In contrast, a downhole motor uses the drilling fluid (which is always being pumped through the drill string in any case) to generate drive energy for the bit.

This is achieved through the well thought-out shape of the rotor and stator in the power section of the motor. The rotor and stator form a large number of closed chambers into which the drilling fluid is pumped. The fluid must pass through the motor but it can only do this by causing the rotor to turn in a similar way to that in which people would push their way into a department store through a revolving door.

The most powerful representatives of our downhole motors can develop a commanding 750 kW (that is, 1,000 hp!) and, thus, easily put Michael Schumacher’s Formula One racing cars in the shade. The fastest types achieve bit speeds of over 1,200 rpm.

The rotation of the rotor is transferred to the „Drive Shaft“ of the bearing assembly by a flex-shaft. The „Drive Shaft“ forms the output shaft of the motor, and the bit is screwed into the lower end of it. It is fixed in the bearing assembly by a number of different bearings. Stabilizer pads are often located on the outside of the motor which centre the motor stably in the borehole.

We have not yet mentioned a small but particularly important detail, namely the kick-off sub on the flex joint housing. If the string starts rotating during drilling
(60 to 100 rpm are usual), the kick-off sub on the motor rotates too. This may look a little “eccentric” but otherwise has no significant effect on the drilling process; the downhole assembly drills straight ahead. However, if the string rotation is stopped and drilling continues solely using the drive power of the downhole motor, the kick-off sub which is now pointing stably in a specific direction, causes a curve to be drilled in the direction of the kick-off. By joining straight and curved sections together it is possible to realize almost any borehole alignment required.

However, we are not resting on our laurels. Quite the opposite! Since the end of 2002 we have had an additional fleet of motors on the market, the so-called "X-treme" motors with an output which is a further 60 to 100 percent higher. X-treme motors are used everywhere where a "normal" downhole motor reaches its limits. This involves, for example, particularly jerky applications with severe vibrations, especially hot boreholes or particularly hard formations.

The name Navi-Drill, which we use for our downhole motors, comes from the fact that we can drill with it and simultaneously navigate the bit through the rock.

Of course, our “Navi-Drills” have been improved constantly during their 30 years of existence and adapted to increasing demands. In the mid-90s the decision was even taken to revise and improve the whole fleet of motors from the bottom up. The result of this work is the “ULTRA” generation of motors, which is considered the most robust and strongest fleet of motors to date in the industry.

The difficulty arises, if we try to drill a curve without string rotation. If the rotation of a several kilometer long drill string, usually weighing umpteen tons, is actually stopped for orientated drilling, the string suddenly rests motionless on the bottom of the borehole and can only be pushed further forwards with great difficulty. More and more pressure is applied to the string from the surface until it finally slips forward with a jerk. However, a jerk like this can quickly become all too violent with the consequence that the bit is pressed so forcefully into the rock that the downhole motor stalls. The bit then has to be picked up, off the bottom of the hole, again before the next attempt can be made, hopefully this time with greater success.

Oriented drilling is therefore more laborious than rotary drilling and also proceeds more slowly. Of course, you can try to minimize the oriented intervals, but it is not only be pushed further forwards with great difficulty. More and more pressure is applied to the string from the surface until it finally slips forward with a jerk. However, a jerk like this can quickly become all too violent with the consequence that the bit is pressed so forcefully into the rock that the downhole motor stalls. The bit then has to be picked up, off the bottom of the hole, again before the next attempt can be made, hopefully this time with greater success.

Oriented drilling is therefore more laborious than rotary drilling and also proceeds more slowly. Of course, you can try to minimize the oriented intervals, but it is not
possible to dispense with oriented drilling altogether, certainly not when undertaking directional drilling with downhole motors. Changing direction without switching off the string rotation is not possible. And that's all there is to it!

But wait a minute! When this statement was made the INTEQ-development engineer jumped up, shouted angrily: “EVERYTHING is possible!” and developed the AutoTrak-System, the most elaborate, cleverest and most complex drilling tool ever invented. Using the AutoTrak-System it is possible for the first time to make any directional changes required without having to interrupt the string rotation. It, therefore, always drills at maximum speed regardless of whether it is continuing straight or producing the desired shape of curve. During this, the AutoTrak constantly evaluates the inclination and direction of the borehole and not only evaluates vibration in the drill string during the drilling process but also various characteristics of the rock and then passes this information on to the surface.

However, the AutoTrak System does not only talk to our directional drillers, the communications also work in the opposite direction, from the rig to the AutoTrak tool in the hole. The directional driller can command the AutoTrak drilling system at any time, and without interrupting the drilling process, to make it start drilling in a different direction from what it was previously drilling, or for example to change the radius of a curve. Our engineers have thought out a clever procedure for communications from the rig to the AutoTrak-tool in the hole.

First, our directional driller enters the command required into a computer on the surface. Second, the computer codes the command in that – like using Morse code – he translates it into a sequence of “dots” and “dashes”. The coded sequence is now transferred to a bypass valve at the upper end of the drill string.

A “dot” means that the bypass valve is opened so that a part of the drilling fluid is squeezed out of the string.

A “dash” means that the bypass valve is closed again and the entire drilling fluid is routed through the string to the AutoTrak tool.

The AutoTrak tool has a power turbine on board which is driven by the drilling fluid. As a consequence of the fluctuations in the drilling fluid, which the bypass valve produces, the voltage also fluctuates. The computer in the AutoTrak tool can understand these fluctuations in voltage: less voltage means “dot”, more voltage means “dash”; thus the “Morse Code” is decoded and our AutoTrak actually continues drilling in the new direction required.

You find this type of communication rather complicated? Well, that might be true at first glance but unfortunately it really cannot be done more simply. This group of problems will be discussed in greater detail in chapter 3.2.

But to return to the current topic: how is it possible for AutoTrak to drill in all the directions required despite continuing string rotation? There is a sleeve at the lower end of the AutoTrak system, which is decoupled mechanically from the drill string. In other words: The entire drill string including the AutoTrak rotates during drilling, only the sleeve does not turn with it. In fact, it clamps itself in the hole via three extending steering pads that allow it to slide forwards and backwards, with the string, but it is practically unable to rotate with the string.

There is a hydraulic cylinder under each of the three extending pads. The higher the oil pressure in the cylinder is, the stronger the force is with which the pad is pressed against the borehole wall. If the oil pressure is approximately the same in all three cylinders, all the pads will be pressed equally strongly against the wall and AutoTrak bores straight ahead. However, if the oil pressure in the cylinders differs, the stronger pads press the
A downhole tool to one side and a corresponding curve is drilled. A computer controls the oil pressures under the pads automatically, so that the bore remains precisely on the planned course.

A downhole tool with the capacity to monitor its own three-dimensional directional drilling performance and correct it independently if necessary (i.e. without intervention by the directional driller) did not exist previously in commercial drilling technology. AutoTrak has thus entered new territory as regards to technology.

The first AutoTrak downhole tools were about 12 meters long and consisted of more than 1,000 mechanical and hydraulic components plus about 2,000 further electronic components on 25 densely packed printed circuit boards, which in turn were wired together by several 100 meters of cable. In the meantime, the design has been revised completely again bearing in mind all the experience gathered. The result of these efforts is our new “AutoTrak 3.0” System, a drilling system which, although it is very similar to the “old” system insofar as its function is concerned, is significantly more flexible and even more reliable than its predecessor because of its modular design.

The main advantage of drilling with string rotation is that a drill string weighing many tons which rotates can be advanced much further into a horizontal reservoir than a string which does not move. Secondly a rotating drillpipe also swirls the debris about which otherwise would settle at the bottom of the hole in horizontal boreholes and, in the worst possible case, could even cause the entire string to become stuck. AutoTrak is enormously flexible, thinks three-dimensionally (can drill in all directions) and was designed for relatively small borehole diameters such as are usual when drilling into deep reservoirs. However, before the long horizontal section of a production well can be drilled, it is necessary to produce the vertical part of the hole, which is also often several kilometers long (from the ground level down to the deposit). In this upper section (the technical expert refers to the “Top Hole”) the hole should simply have a path which is vertical and as straight as possible be-
cause this is the shortest and fastest way to the target. Adhesive friction does not occur in a vertical hole (or only to a minor extent) and no debris can settle on the underside of the hole because there is no underside. String rotation is not required to drill the top hole section!

INTEQ has developed the VertiTrak System especially for drilling the top hole, an automatic drilling system which makes its way down to the reservoir by the shortest route. Without string rotation, the walls of the borehole are hardly subject to any mechanical stress, and therefore the entire hole remains much smoother and in gauge. Employees from Celle will still remember the predecessors of today’s VertiTrak system under the designations “Vertical Drilling System (VDS)” and “Straighthole Drilling Device (SDD)” from the days of the famous KTB research borehole in the early 90s.

So, as we have said, VertiTrak is designed in such a way that it can work entirely without string rotation.

“Just a minute... the drill bit at least must still rotate!”, we hear all of you shout at once. Yes, that is correct. And therefore VertiTrak has a power section similar to the one already described in the section about drilling motors. It must be extremely powerful because the upper part of the hole has a much larger diameter than lower down in the reservoir, and therefore a great deal of stone has to be crushed.

The VertiTrak System has three pads on the lower part of the housing (similar to AutoTrak). It uses these pads to push itself back, again and again, to a vertical position as soon as the smallest deviation of the hole from the vertical occurs. The hydraulic oil pressure for operating the control pads is generated by a pump in the head of the drilling system. The inclination sensor and the evaluation and control electronics are also located there which constantly allocate the correct oil pressure to each pad to keep the well vertical.

Down in the reservoir, where the rotating AutoTrak System is used, it is an advantage to have as many sensors in the string as possible which tell the directional driller whether the borehole is still in the area of the most promising oil or gas yield. In the top hole, where the non-rotating VertiTrak System is used, in contrast, it is relatively unimportant as to which rock types are being drilled through at the time. The important thing is to drill down as fast as possible. Therefore VertiTrak can also manage without having expensive sensor systems on board.

VertiTrak does not need to worry about the direction of the hole but simply has to keep the inclination constantly on “zero”. Therefore, VertiTrak does not need such a complicated “brain” as its little brother AutoTrak does for its complex, three-dimensional “designer boreholes”.

As a whole, VertiTrak is, so to speak, the fat big brother of AutoTrak. It is much stronger, less intelligent, but therefore very robust and significantly cheaper. AutoTrak always drills in rotary mode with string rotation and in this way can get anywhere. In contrast, VertiTrak drills entirely without string rotation and only ever vertically downwards. In Argentina, for example, the rock formations lie at such an oblique angle over the reservoir that all the conventional downhole systems were kicked-off sideways and could only be brought back to the target path by considerable correction work.
“Coiled Tubing” means just what it says. Exactly what that is will be de-
mystified shortly. But, first of all a few other things.

“In the beginning was...”, the situation with directional drilling. To
remind you: A bit and a kick-off motor
are used to enable the system to be
steered in every desired direction via
the drillpipe, just like using a steering
wheel. This is the same principle as
driving an automobile, except that of
course the directional driller must
remain on the surface whilst the hole
gets deeper and deeper. It is then only
necessary to trip the drill string in the
hole and start drilling. Or is it?

Now… from the point of view of
the drillers, the matter may look some-
what different. Entering the borehole
means first of all an apparently end-
less process of screwing the drillpipes
together. A “stand” (see chapter
Introduction) is usually 30 meters
(100 ft) long. If a depth of four kilo-
meters is to be drilled, therefore 130
threaded joints must be screwed
together one after the other and
lowered into the borehole before the
bit finally arrives at the bottom and
drilling can commence. This means
that the protection caps must be
removed from each section; the
thread must be lubricated, screwed
together and torqued up to the cor-
rect value. An installation of this type
requires 3 people working for a half
day without interruption. And then,
when drilling can finally start, in some
circumstances the bit is already blunt
after one day and everything has to
be removed and reinstalled again...

“Oh… the cost of it all!”, screams
the drilling contractor in desperation.

“Is it not possible to get through the
whole four kilometers in one go
somehow? Like a garden hose being
wound on to a reel?”

This idea is not at all wrong for
some drilling applications. In fact, this
is how the first Coiled Tubing Systems
were set up, the drill string of which
actually consisted of long steel hoses
wound on to large reels instead of
individual drillpipes. Since more flex-
ible tubing is also thinner and there-
fore weaker than a “normal” string, it
is only possible to take relatively
small drilling motors down it. The
holes drilled with the system are cor-
respondingly small and have a maxi-
mum diameter of 4 1/8 inches, i.e.
roughly 10 cm.

Now if we hang our
drilling system on this
“steel garden hose” and
unroll it, we will be at
the bottom of the hole
in a trice without
having to screw threads
together. The four kilo-
meters can be man-
aged by one single
man in less than five
hours winding time!

Everybody is satis-

could turn the entire reel with the uncoiled pipe at the top of the well, the flexible steel hose would be too elastic to pass on a steering movement downwards to direct the kick-off on the motor.

So how can the motor be turned in the direction required to drill a curve?

Our engineers developed an elegant solution, the hydraulic orienter. The coiled tubing hose has a fixed length with no thread. It is perfectly possible to insert an electric cable into a hose of this type with which a small oil pump is operated underground. The hydraulic oil from this pump moves a piston to the right or left, on the end of which the downhole motor itself is to be found. So the directional driller on the rig only needs to move a joystick to the left or right and the kick-off drilling motor deep down in the hole turns in any direction required.

The coiled tubing pipe therefore contains a power cable which connects the special drilling assembly (we call it CoiTrak) directly to the control station on the surface. In addition to the power supply for the orienter, this cable link also offers an elegant facility for “online” transfer of every possible item of evaluation data from the hole to the surface. The CoiTrak drilling assembly is therefore fitted with a number of sensors which measure, for example, the hole path, the nature of the rock and the strength of the vibrations underground (you will find the details of how that works in chapter 4 of this book) and send these data via the cable to the surface in real time. That means that every deviation from the planned drilling path and every interruption to the smooth drilling operation can be detected immediately by the directional driller and corrected.

A particularly interesting area of application for our CoiTrak System is the many old wells, deliveries from which have dropped to the boundaries of economic viability in the course of time. Instead of closing these wells, an attempt can be made to crank production up again. One possibility, which is frequently utilized, is designated “Re-entry Drilling”. During this process one or more sideways “arms” are drilled from the existing well into areas of the reservoir which had previously been disregarded. Re-entry holes of this type are an ideal area of application for our CoiTrak System, because they must be undertaken quickly and at a reasonable cost and must manage with little space on the surface.

We learnt in the preceding chapters how drilling of curves is undertaken. But how do we actually know where we are drilling? What tells us if we are on the planned drilling path or whether we have perhaps accidentally come off course? Our directional driller is still sitting on the surface on the rig whilst the bit is burrowing through the rock several kilometers below us. How can the directional driller see what is going on “down there”?

The answer to the question about the path of the borehole is provided for us by the “MWD”-System. MWD stands for “Measurement While Drilling”. The MWD-System consists of a tube which contains various electronic evaluation tools, including a plumb line and a compass. The outer tube of an MWD-System is instantly noticeable because, unlike most other tools on our shelves, there is no rust at all on it because it is made of special non-magnetic steel. As is well known, the compass needle, which is to measure the direction of the well, attempts to align itself with the weak magnetic field of the earth, which is still present, even deep underground. “Normal” steel in the area of the compass needle disrupts this measurement or makes it totally unusable and therefore may not be used as the housing for the
MWD-System. The plumb line measures the inclination of the borehole. The drilling engineers have agreed that a vertical hole has the inclination 0 degrees and a horizontal one the inclination 90 degrees etc.). Whenever a new run of drillpipes is screwed on to the drill string, the MWD-System uses the short moment of stillness in the borehole to measure the inclination and direction particularly precisely. The technical expert talks about performing a “Survey”. Our directional driller on the rig calculates the precise path of the borehole to date from the survey data. Apart from the inclination and the direction (“azimuth”) of the borehole, the MWD-System also has the task of establishing the direction in which the kick-off sub of the downhole motor, the “Toolface” is pointing at that precise moment because our directional driller needs this information to control the drilling operation. Inclination and azimuth therefore provide information on what the hole drilled to date looks like, whilst the toolface determines the direction in which drilling will continue. To realign the kick-off sub on the motor (the „toolface“), the directional driller simply turns the drill string (and therefore also the downhole motor) cautiously a little to the left or the right. One further question arises: the MWD is at the bottom of the hole, maybe several thousand meters deep whilst the directional driller is standing at the top on the rig. How do the measured values actually go from the MWD to the directional driller? As data transmission by cable in the screwed together drill string or via radio through the rock has proved problematical, it was possible to implement a different variation: the transmission of the measured values in the form of targeted pressure fluctuations in the drilling fluid. As you know, this is pumped constantly through the drill string to the bit to pick up the cuttings there and deliver them to the surface through the annular gap between the drill string and the borehole wall. Now, there is a valve in the MWD which is operated (i.e. opened and closed) by a computer, also housed in the MWD. If the valve is “closed” (one part of the flow cross-section still remains free …), the pumps at the top on the rig must generate more pressure to keep the fluid in motion than is the case with the valve open. Thus the valve can generate fluctuations in pressure in the drill string by opening and closing. The expert prefers to talk about “pressure pulses”, therefore, the valve in the MWD is called a “pulser valve”. But … a valve that can transmit measured data? How is that meant to work?

First of all, the measured values are converted into a “binary code” by a computer in the MWD. This is the computer language which, instead of consisting of
many different letters or numbers, only consists of zeros and ones. It is a similar situation to Morse code which of course only has dots and dashes but yet any desired words and sentences can be transmitted with it. So the computer begins to open and close the valve in a specific time sequence. For example, the open valve stands for a zero, the closed one for a one. Whenever the valve closes in the MWD, the pressure rises in the entire drill string. When the valve opens, the pressure drops back to its original value. Right at the top of the drill string (about where our directional driller is waiting for his data) there is a pressure sensor which measures the pressure fluctuations in the drill string and passes them on to a computer connected to the system. This evaluates the measurement by first of all decoding the binary code (much pressure = “1”, little pressure = “0”) and then converts it into actual measured values shown.

Our most recent MWD-System is called “OnTrak”. In addition to the sensors already described for procuring the directional drilling information (inclination, azimuth and toolface) it has further “sense organs”. The measurement of the pressures in the drill string and in the borehole gives information about the stability of the borehole and tells us whether the discharge of the debris from the hole is working in the best possible way. The measurement of the natural radioactivity and conductivity of the rock enables information to be gained on exactly which rock is being drilled at present and whether gas, water, or oil is to be found in the pores (this will be described in greater detail in the following chapter). Finally, a vibration module indicates whether the drill string with the sensitive evaluation systems is rotating evenly deep down in the hole or is vibrating dangerously.

Well, so much technology is hidden in some of the “tubes” on the shelves you see on our company site. Could you have imagined that?

OK, we know now where we are drilling to. But the drilling path originally planned is not always the best one. For example, the reservoir could in fact be a little higher or lower than the geologist thought. In this case we might drill past the reservoir altogether! Or it could be that by chance, at the particular point in the reservoir in which we want to place the well, the pores in the rock are particularly thin and we would therefore only be able to deliver a very small amount of oil, whilst a few meters to the left or right, the really good big pores remain unnoticed.

Is there perhaps some way of establishing when drilling the current path of the well is advantageous or whether it would be better to modify it a little? I’m sure you already suspect it: yes, we can find out! Modern drilling assemblies have a wide range of well thought out evaluation systems on board which enable us to obtain valuable information about the nature of the rock in the hole. If the path of the borehole is constantly optimized during drilling on the basis of the results of the evaluation, the technical expert calls this “Geosteering”.

In the chapters which follow, you will learn about the most impor-
At the beginning of this book we described how and where oil and gas can be created. It was explained there that the oil or gas tends to collect in sandstone under “covers” of clay. As the gas is the lightest, it is to be found at the top in the reservoir, i.e. particularly close to the clay layer above it. Therefore it is particularly useful when drilling for natural gas to have a sensor in the drilling assembly which can inform the directional driller, on the surface, whether the drilling assembly, far below in the earth, is still in the sand of the deposit containing gas, or is in the clay cover above it.

There actually is a sensor which can do that! This involves a Geiger counter! No doubt you know this sort of equipment from physics lessons at school, it is used for measuring radioactivity. If the teacher had held the Geiger counter against a hidden radioactive sample, which no-one was allowed to touch, the Geiger counter would have started to crackle like mad.

“Just a moment”, you will perhaps now ask, can a Geiger counter distinguish between sand and clay? How does it do it?" The answer is easily found: many types of rock are naturally slightly radioactive. This is normal, and quite safe to humans. Different formations also emit radiation to different degrees, clay, for example, significantly more intensively than sand. When the Geiger counter on board (in the technical world it is called a “gamma detector”) reports relatively strong radioactivity, then we are moving towards the clay layer and had best move away. On the other hand, if the gamma detector is quiet, we are drilling in the sand.

The oil or gas of the reservoir sits in the pores of the rock. It is therefore entirely obvious that rock which has larger pores can also contain more oil or gas. If, on the other hand, the pores are thin, we will not be able to pump any large delivery flows above ground from this rock. Therefore the measurement of the pore size during drilling provides extremely important information whether we are in a “good” or “bad” area of the reservoir. Therefore, our engineers have developed the “APLS”. APLS stands for “Advanced Porosity Logging Service”. Anyone who uses this service, not only receives an evaluation of exactly how porous the deposit is, but also information on what the pores are actually filled with. Granted: the underground determination of the porosity is not simple and our scientists had to dig very deep in their bag of tricks to find a suitable measuring principle. Oil and gas are “hydrocarbons”, that means, they consist of carbon and hydrogen atoms which have combined together in specific arrangements to form chains or rings.

Water (as you know, the chemists call it H₂O) also contains hydrogen (a water molecule consists of one oxygen atom, which so to speak holds a hydrogen atom with each hand). Therefore, regardless of whether oil, gas, or water is present in the
pores, there will always be hydrogen atoms present. In contrast, the surrounding rock contains practically no hydrogen.

The proportion of hydrogen in a formation, the academics concluded, can therefore be used as a scale for its porosity: no hydrogen — no pores, a lot of hydrogen — lots of pores. That is good because the proportion of hydrogen in the formation can actually be measured if you use an artificial radioactive source and a detector.

Let us have a look at what happens when a radioactive substance, to put it more precisely a neutron source, is held against a sample of rock. Neutrons are a constituent part of radioactive atoms. They release themselves from the radioactive source and shoot into the environment with great energy. They bounce off the atoms which they meet on their way through the rock. Each impact process causes a part of the original energy of the neutron to be lost. A collision with a hydrogen atom costs the neutron a particularly large amount of force.

After for example 10 collisions with hydrogen atoms, the entire energy of the neutron has fizzled out. You remember of course: hydrogen only occurs in the pores. The more pores there are in the rock, consequently the more neutrons give up, exhausted on their way through the rock.

In a low hydrogen formation (i.e. if there are only a few pores in the rock) the neutron does much better. Here it is brimming over with energy even after one or two hundred collisions with the atoms of the rock.

Now this effect can be used to measure porosity. A detector is installed at a specific distance from the neutron source which measures how much residual energy the neutrons still have after their migration through the rock. In poreless rock the neutrons arrive at the detector full of energy. In contrast, in porous rock the few neutrons arriving are significantly more “lifeless”. In gas they can just survive but if the neutrons have to pass through pores which contain oil or water they are at their last gasp.

So a great deal of energy at the detector means “no pores” in the rock, little energy means “pores with oil”, and even less energy means “pores with water or gas”.

That’s very neat isn’t it? However, our specialists are still not satisfied because this “simple” measuring principle on its own is open to too many possible interpretations. For example if the energy content at the detector drops this can mean that:

a) either the proportion of pores becomes larger and therefore more hydrogen is present in the rock,

b) or the pores do NOT become larger rather there is simply more water (and therefore less oil) in the pores because water swallows up more energy than oil or gas.

How unfortunate, you could think, because you still cannot be sure! Which of the two answers is the right one? But of course our scientists soon had another solution ready. Not only are there radioactive sources which...
emit neutron beams but also those which emit gamma radiation. Gamma radiation has quite different characteristics from neutron radiation. You could compare neutron radiation to billiard balls which collide with other balls (atoms) and cause these to move. This is why the neutron loses a little energy with each collision. In contrast, gamma radiation has no mass (generally referred to as “weight”) like a billiard ball and cannot therefore push forward any nuclei. Instead, however, gamma radiation can cause the electron cloud of an atom to “swirl about” or even tear individual electrons out of the cloud. You remember that an atom consists of a nucleus and an electron cloud which circles around this nucleus. During this “swirling about” by the electron cloud, the gamma radiation loses energy, the radiation is weakened. It is fortunate for our measurement that gamma radiation reacts first and foremost to the atoms of the rock and much less to the atoms of the substances contained in them. The less porous the rock is, the more often the gamma radiation strikes atoms of the rock on its way to the detector and the weaker the signal at the detector is. This is exactly the opposite to the situation with neutron radiation.

The combination of the two evaluation systems (neutron and gamma radiation) now finally produces the full picture required. If we assume, for example, that we are drilling from an area with oil-filled pores into an area of water-filled pores (which is normally undesirable), but the porosity remains the same, it becomes apparent because the detector shows that the energy from neutron radiation has decreased, whilst the energy on the gamma radiation detector remains constant. In contrast, if the pores in the rock remain filled with oil but are getting smaller and smaller (which is also undesirable) as the borehole progresses, the energy at the neutron detector increases (fewer hydrogen atoms) and falls at the gamma detector (more rock). So, with a little brain work, sensible information on the porosity and the distribution of the contents of the bores along the borehole can be produced from the different signals of the two detectors. The designation APLS (Advanced Porosity Logging Service) actually strikes the core of the matter precisely.

Some measurements can actually also be undertaken without using radioactive sources. For example, if you only want to know whether the pores contain the coveted oil or gas or only (salt) water, then a simple radio transmitter in the drill string can do amazingly good work.

The transmitter transmits a certain radio signal which is picked up again by two receivers at different distances away. Oil is a relatively poor conductor of electricity; therefore, it is also difficult to transmit radio waves through it. In contrast, salt water is an excellent conductor of electricity and radio waves.
on whether the pores in the area of the evaluation system contain oil or water at the time, reception is better or worse.

In the technical world, instead of talking about the “conductivity” of the rock, its reciprocal value is normally used, the “resistivity”. If the conductivity is high (salt water in the pores) the resistivity is low and vice versa. In principle, our experts on the rig only need to assess the quality of the reception to draw conclusions about the nature of the natural resources found.

Have you ever seen a magnetic resonance tomograph? If so, it was probably in a hospital. A device of this kind is about 2 meters high and 3 meters long, an enormous monstrosity.

Why am I talking about this? Well with a magnetic resonance tomograph, you cannot only take photographs of sections through the body but you could also undertake very interesting measurements in the borehole if you could somehow force the monster machine down there. Most boreholes actually only have a diameter of 15 to 20 cm.

In fact constructing a magnetic resonance tomograph for these dimensions was a problem which remained unsolved for a long time, but - I am sure you have guessed – the engineers from INTEQ finally cracked this problem too.

In comparison with other measuring methods, magnetic resonance tomography (we usually tend to call it “NMR”, that is the abbreviation for „Nuclear Magnetic Resonance“), is a complex measurement which, although it can only be implemented underground at great expense, does permit a number of different characteristics of a reservoir to be investigated at the same time. With MagTrak (that is the name of our evaluation system) we can measure the porosity of the formation, determine the permeability of the rock (i.e. whether the pores are connected together in such a way that the oil or gas can flow) and establish the distribution of the pore sizes within the rock. With MagTrak we can also measure the distribution of the fluids in the rock (oil, gas and water) and their respective proportions can be calculated. As a consequence, we are in a position to give our customers a better answer to a few of their burning questions: Is oil or gas present in the deposit and, if so, how much? And how effectively can the oil or gas be produced?

OK, in the preceding chapters we have learnt that we can answer almost all of these questions with other measuring methods but to do this we would always need several items of evaluation equipment at the same time, some of which also contain radioactive sources. In contrast, the NMR-measurement manages to do this without using radioactivity, even though the word “Nuclear” is part of its name. In this way, it forms an important alternative to the classic porosity measurements without the burdensome risks and safety requirements.

Well how does MagTrak work then? Some atoms behave like small magnets, which means, that like a compass needle, they always align themselves so that they point in the direction of the magnetic field lines. Hydrogen atoms have this characteristic for example. As hydrogen is to be found in practically all the pores in the rock (i.e. in water, oil, and gas), this characteristic can be used for various measurements.

Hydrogen atoms, in the pores, are all aligned in the direction of the earth’s magnetic field. Now, if an arti-
cial magnetic field is suddenly generated, which points in another direction and is stronger than the original one, the atoms will turn in the direction of the new magnetic field, but flip back to their original position when it is switched off.

The “echo”, generated by the atoms “flipping back” can be measured. The smaller the pores in the rock are, the faster the echo decays, so this provides a method of measuring the pore size.

The “volume” of the echo is a measure of the number of atoms flipping back, as the pore size is already known it is possible to conclude from this measurement whether gas, water or oil is present in the pores.

All further measurements, such as how mobile the fluids in the pores are etc, are the result of clever mathematical/physical methods of evaluating the measured values. The engineers probably would not have thought of it at all, but that is why we also have many clever physicists, mathematicians and other scientists in our development department.

In order to be able to evaluate whether the oil or gas delivery from a newly discovered reservoir will be worthwhile or not, it is necessary to know how high the reservoir pressure is. We have developed our TesTrak tool for this purpose.

Previously we flirted with the name „Mosquito“ for this tool. This name appealed first of all because TesTrak extends a sort of proboscis to measure the reservoir pressure – something like a midge biting – with which a sample of the reservoir fluid is sucked out.

During this, it is not the fluid sucked out which is investigated, but rather the extraction process is observed and evaluated. At the beginning of the measurement, a pump on the tool side of the suction proboscis sucks and this generates a certain negative pressure against the borehole wall. When the pump is shut off, it takes a while for the pore fluid to flow out of the formation and into the proboscis, equalizing itself with the reservoir pressure. The ability of the pore fluid to flow can be deduced from the duration of this pressure equalization process, the longer it lasts, the more poorly the coveted raw materials flow (and the lower the production from the reservoir will be).

The special feature of our TesTrak tool is that for the first time the pore pressure can be measured directly during the drilling process, and not only after completion of the borehole, using a special evaluation system, which is brought into the borehole on a power cable. This, in fact, costs much more time and money and furthermore the information gained can no longer be used to optimize the path of the well.

Of course, our TesTrak tool is only accepted by our customers as a constituent part of the drill string, if it does not impede the drilling work too much. This is easier said than done. As long as the suction proboscis is occupied with the sampling process, the drill string...
may not move. And a stationary drill string is normally a red flag to our drilling contactor who wants first and foremost to drill and not to measure. So the measurement must take place quickly, not only because of the immense costs of a drilling system but also because of the possible risk of the drill string becoming stuck in the borehole (differential sticking). A period of 5 minutes for measurement should not be exceeded in any case, that corresponds approximately to the time taken to screw on another drillpipe to continue drilling.

However, in addition to the speed of the measurement, the accuracy of the measurement is also of vital importance. The absolute accuracy of the pressure measurement must be less than 0.5 bar (note: 1 bar is about 14 PSI) with an accuracy of replication of less than 0.1 bar and a resolution of 0.01 bar – and all that at absolute pressures of 1 – 2,000 bar! These requirements are far removed from “normal” measuring tools, the quartz pressure sensor that can do this cost as much as a small automobile with good quality extras!

To be sure that the measurement is correct, it is repeated three times in succession in the short time available. The good correspondence of the measurements reminds us each time we use it that once again our engineers have developed an exceptionally reliable measuring tool.

The majority of oil and gas wells will be between 3 and 6 km deep and not usually vertical, but often at an angle in the lower section or even horizontal. The preceding chapters have described in detail how the high art of directional drilling functions.

A well is not very large; its diameter is often only 8½ inches, which is just a good 20 cm. Of course, the drillpipe has to have an even smaller diameter so that the cuttings can still be carried above ground between the drill string and the borehole wall. A diameter of 5 inches is usual here, i.e. 127 mm. A diameter of 127 mm is not much if you remember that at the same time the drill string is, well … let us say 5 km long. The length of the drill string is therefore about 40,000 times greater than its diameter.

A single drillpipe 10 meters in length, standing on the rig, appears solid and rigid at first glance. However, the drill string at its full length behaves more like a flexible, thin wire.

Just imagine that you wanted to install a satellite dish on your house. There is even an empty pipe already there for the cable required. This empty pipe runs vertically down from the chimney through several floors until it reaches the basement, there it changes direction and runs horizontally along the basement ceiling thought the floor to the electric box in the utilities area. The dish on the roof is quickly installed and the cable is ready to thread through. It slides down vertically into the basement almost on its own, the lower it goes the heavier it is and pulls the rest through with its own weight.

But then things get tense. The cable can probably simply be pushed around the bend but then we have to play tricks and twist it around to get it to go further. And if we turn the cable or apply pressure to it up on the chimney, that certainly does not mean that down in the basement, the cable is doing
the same thing.

The situation in a well is exactly the same, the drill string may be turning calmly and evenly on the surface but that doesn’t mean that 5 kilometers further down in the hole everything is going smoothly. Who knows? Perhaps the bit is sticking now and then, tears itself free a moment later and then makes up the missing revolutions of the string may be turning calmly and evenly on the surface but that doesn’t mean that 5 kilometers further down in the hole everything is going smoothly. Who knows? Perhaps the bit is sticking now and then, tears itself free a moment later and then makes up the missing revolutions of the string by jerking and hammering until the game starts again from the beginning. If it was like that, the drilling assembly would definitely not last very long. But – as we said – from the surface normally you don’t know what is going on down in the borehole after damage to or destruction of the drilling assembly, it is only possible to find out the cause of the problem after the event via a detailed examination of the damage.

Now, I’m sure you have guessed: of course, our clever engineers invented and “underground eye” with which we can “see” exactly what is going on deep down in the borehole: the CoPilot. At first glance, there is nothing exciting about the CoPilot module. It is a piece of pipe with threaded connections. However, on closer inspection the sensation is under the sleeve covering the tool. There, everything is stuffed full of sensors and electronics.

The sensors for measuring the load on the bit, the torque and bending moments are particularly worth mentioning. These are based on so-called strain gauges. These are small grids of metal which are attached to the CoPilot tool using a well thought out plan and connected together electrically. Under the influence of outer forces, the material of the tool expands or is compressed. During this the grid rods attached with adhesive either become slightly longer and thinner or shorter and thicker. This deformation of the grid results in an extremely small change in electrical resistance which can be detected by very sensitive electronics. This measuring principle works, even in the extreme conditions in the borehole, where temperatures and pressures form considerable interference dimensions for which compensation has to be made at great expense. The CoPilot measures a total of 14 sensor channels continuously and at very high frequency (accelerations, forces, pressures and temperatures) and files the measured values in the memory in the tool. So far, however, all that is nothing special, our competitors’ equipment can manage this too.

The fact that the CoPilot not only stores the massive quantity of measured values but evaluates and assesses them on the spot is completely new and has no competitor in the marketplace. As long as everything is OK, the CoPilot reports “everything in the green area”. However, if dangerous disruptions to the drilling operation occur, the CoPilot gives the alarm. On a screen in the rig suddenly for example “Warning, Bit Bouncing” appears. That means that the bit is bouncing on the bottom of the hole instead of turning evenly. Other messages can relate to the fact that the string is bending too far or the drillpipe is swirling around in the hole or banging backwards and forwards.

Furthermore, information can be checked with the CoPilot, as to whether the bit loading applied is actually present at the bit, whether the drill head is still cutting well enough and much, much more. The bending moment measurement in the CoPilot tool enables conclusions to be drawn about the curvature of the borehole and warns about “kinks” in the borehole path which can occur e.g. at transitions between different hardnesses of rock.
You can also store the data in the tools and only read them out and evaluate them after the drilling assembly has been removed. But that is a pity because the whole point of putting the evaluation tools in the string is to have the information available during drilling. Don’t you want to use the swimming trunks in your suitcase as soon as you arrive on holiday and not several days later?

Perhaps you are now asking whether the data can be transmitted in some “more modern” way than with such an ordinary pulse valve.

We are interlinked everywhere now with computers and telephones. Isn’t it possible to install a “telephone line” in the drill string too?

Well, as the drill string can consist of hundreds and hundreds of threaded joints that would be a bit like joining together hundreds and hundreds of extension cables to operate a power drill in Wienhausen from a socket in Celle. Moreover, the drill string must be able to be installed and removed quickly in a dirty environment. Finally, every electrical connection contains the risk of a contact fault with the consequence that communications could be lost. That is too risky. Moreover, a cable several kilometers long in the drillpipe could tear and block the drill string which can lead to very dangerous situations in the drilling operation.

“But a mobile phone works without a cable! Can’t the data be transmitted in a similar way?” you will ask.

Correct, attempts are being made to transmit data wirelessly by radio out of the borehole or acoustically via the drill string.

Electromagnetic transmission is used specifically in wells where pressure pulse transmission does not work. That is the case if drilling is being undertaken using “air” or “foam”, i.e. compressible drilling fluids, which cannot pass on pressure waves. The data is then transmitted through the stone by radio. In itself, an electromagnetic transmission is a fine thing, but unfortunately it only works down to a depth of approximately 3 km, however, even then only with such long wave signals that the transmission is just as slow as with a pulse valve. Well ... in that case we might just as well use a pulser which still works at a depth of more than 10 km in advantageous conditions. In principle, data can also be transmitted somewhat more quickly with acoustic methods, for example, small hammers, which strike the drillpipe, but here too, no one
has managed yet to bridge sufficiently long distances. Additional amplifier stations would have to be installed in the drill string. All in all, this too is not much faster than pressure pulses. The amplifier stations increase the cost and also the risk of a fault.

So for the time being, even though we are still researching diligently into other solutions, we are still staying with the “simple” solution of working with the good old pressure pulses.

“It was at least possible to convey pressure pulses through the drill string in a more effective way than in the past so that the data rate could be increased!”, grumbled one of our engineers when he was on a long flight overseas and could not sleep. A few rows behind him, a woman was sitting, who had a particularly noticeable voice which could be distinguished clearly above the general background noise from the other passengers. Whatever you did, this woman’s voice was constantly present and before you realized it you knew half her life story from being forced to listen.

It struck our engineer suddenly like a flash of lightning. The unknown woman embodied the principle for solving the problem!

The conventional pressure pulses for data transmission have the quite serious disadvantage that they work in a frequency range in which most of the “noise” is produced during drilling. Not only the pulser pulses in the frequency range around 3 Hertz, but also the giant pistons of the mud pump and even the rollers cones of the bit generate similar pressure fluctuations which rustle through the drill string. Therefore the voice of the pulser can disappear into the general noise level in some circumstances until it is incomprehensible.

If you could fit up the pulser with a “shriller” voice which rises clearly above the other murmurs of its surroundings, then clear and unambiguous data transmission would be guaranteed, even if it “spoke” somewhat faster!

No sooner said than done, our engineer started to design it. Instead of individual, slow pulses, he allowed the valve to “flutter” on and off at higher frequencies.

Different high tones now serve as “zeros” and “ones” which shrill through the drill string, relatively unimpressed by the background noise, like the striking voice of the woman through the aircraft.

Now if even more different tones (frequencies) are used instead of two, the efficiency of this system can be increased even further.

Yes, here too, INTEQ sets the tone!
In the preceding chapters we have learnt that INTEQ develops and uses a wide range of drilling and evaluation tools. All of these systems are gaining a higher and higher performance, drill more quickly, and save more and more drilling costs in this way.

However, in this analysis, the fact is often disregarded that the use of the best possible technologies is only crowned with success if the “whole caboodle” is harmonized. For example, drilling more quickly means that much more cuttings are produced in the hole. If this is not transported out of the hole properly, then the drill string can be buried and become stuck.

Or another problem: what use is the best possible drilling plan for a long horizontal drilling path, if the drill string cannot be pushed forwards but always buckles when weight is applied from the surface? You will have guessed already: even the best drilling systems cannot replace careful planning of the entire drilling process. This is why we have a development department which deals specifically with the compilation of application and planning software. There is plenty to plan, like: What tilt angle should you set on the directional drilling motor? If it is set too large, the “kick-off” motor will definitely not drill as well as it could in rotation operation, if it is set too small, the drilling assembly may not get round the curve properly. The best possible solution to the problem is dependent in every individual case on the combination of the drilling assembly and the drilling conditions but is always found quickly and reliably by our application software.

Even: Is the drilling fluid heavy enough to prevent a possible inrush of gas into the hole at any time? On the other hand, it must not be so heavy that it crushes the less stable rock strata, enabling the expensive drilling fluid to be lost into underground cracks. Can the drilling fluid still do its work if its characteristics change at great depth or high temperatures? What pressures do the pumps have to generate anyway to ensure that sufficient fluid is transported down through the string, which is several kilometers long, and back to the surface in the narrow annular gap between the string and the borehole wall? Is the bottom of the hole cleaned well...
enough by the jet of fluid emerging from the bit or is the bit wasting energy senselessly by traveling over the same lumps of rock again and again and crushing them to fine dust. Our cleverly designed hydraulics programs know the answers to questions like this and help us to refine the drilling fluid system.

In principle, all the programs used in planning the drilling process can also be used subsequently „online“ to optimize the drilling parameters in situ. For example, if you compare data measured during drilling with the figures calculated in advance, it is possible to detect problems with the discharge of the debris at an early stage.

And that brings us right back to the start: our drilling systems ensure the rapid and reliable progress of the drilling operation, our evaluation tools help us to find the best way and our software plans, monitors and co-ordinates the entire drilling process.

For the drilling contractor this means minimizing the irritation whilst simultaneously maximizing the prospects of success for a project.

He can rely on INTEQ.
And finally
That concludes our tour of the INTEQ Drilling Technology Exhibition. Of course we could not show you all the drilling and evaluation tools our company offers and sells. It is not possible, simply because technical progress moves forward and we have to bring new products faster and faster into the marketplace to keep our leading position in the tough business which is drilling for oil. Regardless of when the book appears, it will always already be a little out of date. A complete description of all our services and products would also soon make this little book swell into a thick tome that no one would want to read anymore.

For today, we hope that this book has given you a few new insights into our company’s products to begin with. We can be really proud of producing unique and reliable high-tech products for a market with unprecedentedly extreme requirements. The insides of many of our drilling and evaluation systems look more like spares for space satellites than components of a „drilling machine“! And new developments continue to drive us forwards. No doubt a new edition will be produced one day which will inform you about the most recent achievements in deep-hole drilling.

Until then, just ask if you don’t know quite how the product functions which you are working on. Your colleagues in the Engineering and Technical Services Departments will be only too pleased to provide you with the information you need.

With regard to colleagues: this book would never have appeared without the unselfish assistance of my colleagues. I would like to offer special thanks to Detlef Hahn, Matthias Meister, Uli Hahne, Hartmut Grünhagen, Roland May, Gerald Heisig and Brian Riley, who have enriched the project with their constructive criticism and technical knowledge.

...Thank you very much!

Matthias Reich
The Divisions of Baker Hughes

Hughes Christensen
Baker Oil Tools
Baker Petrolite
Baker Atlas
CENTRILIFT
Baker Hughes INTEQ
Baker Hughes Drilling Fluids

Baker Hughes INTEQ
Hughes Christensen
Baker Oil Tools
Baker Petrolite
Baker Atlas
CENTRILIFT
Baker Hughes Drilling Fluids

Bohrtechnik U engl_RZ   2
01.12.2004   14:18:28 Uhr
Baker Hughes is a world-leading technological corporate group in the oilfield service industry. Based in Houston, Texas, the company has a presence in over 60 countries and employs around 27,000 people of nearly 100 nationalities. With seven divisions linked to its product lines – Baker Hughes INTEQ, Baker Oil Tool, Hughes Christensen, Baker Atlas, Baker Petrolite, Centrilift, and Baker Hughes Drilling Fluids – Baker Hughes carries out research and development and works for all mineral oil and natural gas producing organizations around the globe.

Over 850 employees are based at the German branch office in Celle. Eighty percent of those work for the INTEQ division, where drilling systems are developed and drilling systems and diamond bits are produced and marketed internationally. Our sales region incorporates central and eastern Europe, Russia and central Asia. Baker Hughes also offers highly specialized services for drilling rigs (particularly for directional drilling). Almost 30 percent of our staff members in Celle are engineers.

www.bakerhughes.com
www.bakerhughes.de