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Design of a Core Holder That Allows Highly Detailed Computer Tomography Scans in 3 Dimensions

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ABSTRACT

In the case of advanced Computer Tomography scanning of rock core samples, there is a need for a good core holder. The core holder contains the rock cores and neutralizes temperatures and pressures against the CT-scanning system. In the case of the core holder that is used for core flood experiments, there are several factors that play against each other. The core holder that will be used for the experiments at the GZB - International Geothermal Centre, will support the core to be flooded by different types of gases and liquids, while having the core experiencing temperatures and pressures that can be expected at the considered reservoir depth. This is expected to be around 150 degree Celsius and 200 bars of pressure.

The real challenge is to make it also fit in the CT scanner, letting the X-rays through with as little adverse influence as possible, and allow for movement around and along the vertical axis.

The CT scanner that will be used is going to give a representative image of all pores down to 1 µm, which means that it is sensitive to any disturbances in both movement and in choice of material. This means that choice of material is important to achieve a stable and transparent core holder. Favored materials for this kind of applications are PEEK, Carbon fiber and Aluminum, due to the low atomic number.

When it comes to the size, the core holder is limited by the space left in the CT scanner, but should be compatible with smaller sizes. This means that the core holder is expected to accept cores that are less than 100mm in diameter, and lengths up to 600 mm long.

1. INTRODUCTION

When it comes to geological studies of porous rocks, for geothermal or other fields of interests, it is important to know what will happen with the rock after time of usage. Will the rock open up or close the pore spaces as fluids or gases are passed through the system. For many applications it is also interesting to know whether you can improve the system, or “clean” an old system after a while of use.

To look at the progression of various methods of exposures to the rock, it is good to use a non-destructive method, which will allow you to analyze the same specimen, over a time lap to detect changes by time. A micro-tomography scanner is one good solution for this as it allows getting a highly detailed picture of the inside, in 3D. With the right machine and systems around you are able to detect differences, inside a rock, that are as small as 5-6 µm. X-rays have been used to look inside things and beings for over 100 years, and as its well-known to use electromagnetic radiation to create an image of an object. Various materials absorb the radiation better than others, and will require higher amount of energy to be penetrated.

With a core holder that is properly designed and constructed, you will be able to see the same resolution as when a rock is not contained in a core holder. This means you can use this to see minerals dissolve and precipitate in a rock. Utilizing this while changing the surrounding conditions and you will be able to simulate in situ conditions. With increased temperature and pressure, the core holder can be used to simulate various scenarios of reservoir conditions, such as continued use of open pores, or to actively stimulate opening of existing fractures and porosity.

The system is planned to be up and running for initial test in the fall of 2014, whereas the core holder will be created during the summer of 2014, to initialize flooding tests and pressure and heat tests before it is mounted inside the CT scanner.

2. PROBLEM

The core flooding system will be used to do studies of the influence of reactive fluids on the rock, and to study the same sample with various time intervals, without destroying the sample. To do this a core holder needs to be designed and constructed to the specifications needed for our planned experiments. The biggest complexity is not to create it, but to get the best possible pictures, without compromising on safety. There is one similar core holder made, which utilizes high grade alloys, by the research department of Shell (Ott, H., 2012).

3. DESIGN

The core holder that will be used for the ordered CT-Scanner will have several points of important functions and features. The main function is to support the rock sample in a vertical position. It will also create a hydrostatic confining pressure and temperature to simulate an “In-situ” situation. Then the advancement in this design is to be able to pass various types of fluids or gases, including highly corrosive fluids. The last features is the most important for this to function in the CT scanner is to make it as x-ray transparent as possible and to allow rotation along the vertical axis. The last design feature is to ease the use and creation of the holder. This is a part of a setup that is not used in large numbers, and is not expected to be produced to a large extent. This means that the core holder need to be easy to maintain with spare parts and easy to use. All the different functions and features will be further explained bellow:

3.1 Vertical Support:

The initial design is made for cores for 40mm diameter. This is a compromise between a large size core holder, around 100mm and a smaller 10mm, to make the pats not too big to handle and not too small to increase production costs. Later there is plan to look at larger samples, as well as smaller, and then adequate modifications will be done.

Inside the core holder there will be two piston-like features, which will work as the support for the sample that will be analyzed. The diameter of these will be same or similar to the sample. That means that they will initially be 40mm, but this setup is expected to accept diameters that are slightly larger or smaller than this. The outside of the sample core will be covered with a tube of various type of material. It is favored to have a shrink tube, which will tighten it up further as the heat is turned up and prevents a connection between the confining fluid system and the pore fluid system. On the outside of the pistons there will also be and O-ring to further increase the seal, so there is no penetration of the confining fluid, into the sample. These two pistons will be different in the sense that one will be in one piece with the cap, while the other will free to move, and there for adapt to various lengths of sample.

3.2 Pressure & Temperature:

Both temperature and pressure will be produced by a external system, and be introduced to the core holder with oil. The oil will enter in either end of the core holder and will exit through the other end. Whether which direction the oil will flow is up to the experiment, but the flow rates are not high to create as little turbulence, which can affect the core sleeve. There was considered to have a static system, which was heated up inside the cell. This was discarded due to the thermal differences that would occur in the core holder.

The oil will enter just next to the Pistons that are the support for the sample. On the opposite side of the oil ports there will be a thermocouple (Type K). The thermocouples are to log the temperatures inside the core holder. Later these will control the external heat source for the oil. There will be at least 2 thermocouples in the system, to make sure there is an even temperature/thermal equilibrium across the length of the sample.

The soft sleeves covering the sample are to allow the oil to put pressure on the core along the X- and Z-axis. The free piston will in its turn provide the pressure along the Y-axis. This means that the sample will be exposed to a hydrostatic pressure.

3.3 Flooding:

The flooding is the feature that makes this stand out from many other core holders, and is planned to allow 2 different mediums to pass through the sample without stopping scanning of the sample. The core holder will be used with a broad set of various fluids and gasses, all from highly corrosive saline liquids to regular water.

To allow for two different fluids to be passed through the sample with a little “dead” fluids and mixture as possible, the idea is to introduce the second fluid into the system as late as possible. This means this will happen just before the fluids are entered into the sample. This means that one of the pistons that provide the support to the sample will introduce two fluids just before the sample. This is naturally made in the piston, which is stationary. Looked at it in cross-section you can see that its two holes that connect into 1 port.

Before the fluids enter the sample, a porous disk will distribute it, placed between the support and the sample. This will not be found in the other end of the sample, as there will there only be an output. In the case you want to use the core holder to run alternating direction, you would also place a porous disk in the end, in the bottom according to the design, of the sample. All the fluid lines in the core holder is made to make as small influence on the flow as possible. This means that the diameter of the fluid lines will match, or try to match, the diameter of the outside fluid system. That will then be the rocks that will be the limiter for the amount of fluids that can be passed through, and not the core holder. For example the current design of fluid system uses ¼ inch tubes, which is close to 6.35 mm, and therefore shall the fluid lines of the core holder match this, and is currently designed with 5mm fluid lines for both confining oil and fluid1 and fluid 2.

As some of the fluids that will be used are highly reactive and will be introduced to the sample with high temperatures and pressures, around 150°C and 200 bars, it is to expect it to have corrosion on the parts. The initial tests and developments are planned to use milder fluids such as low saline water and just regular waters. This means the “wetted” parts of the core holder will initially be constructed in low grade materials like stainless steel and aluminum to later be upgraded to more corrosion resistant materials. This would be when the design is finalized and tests with regular fluids have been successful.

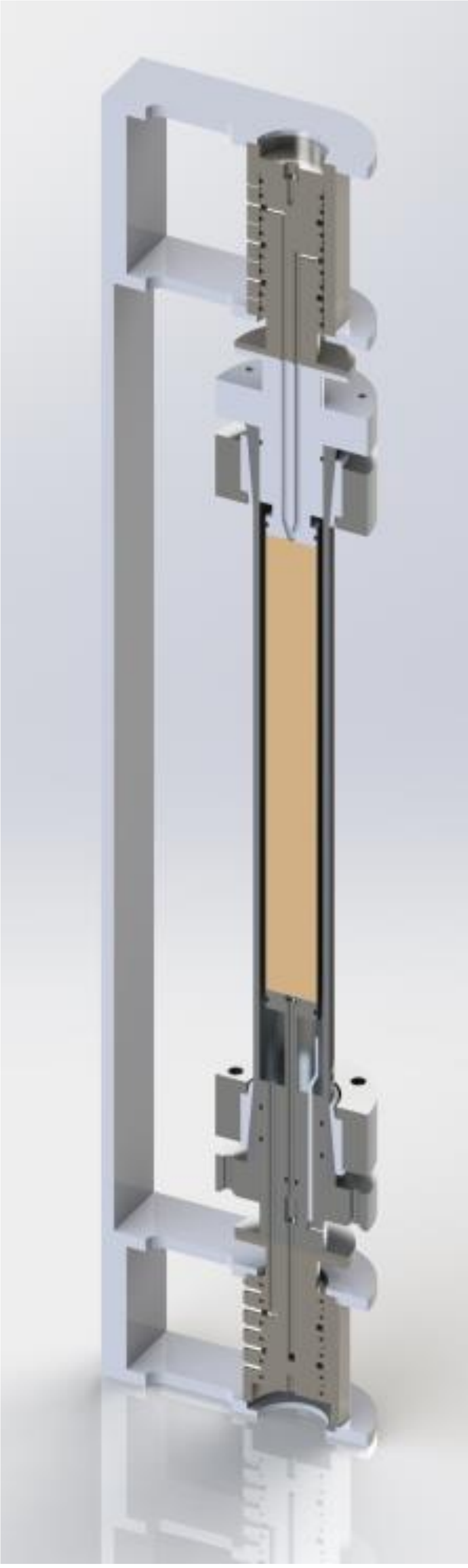

Figure 1: The full assembly of the current design of core holder. Various colors are used to easier visualize different parts. Here it is possible to see the two pistons which provide support and also the vertical pressure to the sample.

3.4 X-ray Transparency:

This is an important feature to make the core holder use full for a CT-scan. As the CT scan is an X-ray which scans the whole sample, it is advantageous to use materials that will not disturb the X-rays. This is why it is important to keep the material and fluids surrounding the sample to the minimum. There will therefore need to be a compromise between strength and X-ray transparency to acquire the best images and still be able to simulate in-situ conditions.

The transparency can simplified be explained with a relation to the thickness and density. The heavier a material is the more X-rays it will absorb. This means that X-rays penetrate aluminum easier than steel, and carbon fiber is more transparent then aluminum.

The use of pure aluminum during the initial tests and scans, and the cheaper price of aluminum makes up for the poor image quality during the test and developing stage. The poor imagery can also be improved by adding a thin carbon layer on the inside of the pressure vessel. This layer can be used to improve the picture computationally by excluding the aluminum from the scans.

This is not as good as using carbon fiber. The problem with carbon fiber has is that is more dependent on temperature than a metal, and is therefore used in a sandwich system with glass fiber and with an aluminum inner tube.

Anything else that might obstruct the x-rays, and occur in a symmetrically pattern, can as well be computer assisted excluded from the images. Though the design has been optimized to reduce the amount of things around the sample. This is the reason of using a "collar" system that put pressure on the caps similar to the design of the Core holder at Shell (Ott, H., 2012).

3.5 Swivels:

An essential part of the core holder, as it will not be fixed and is required to spin to create good 3D imagery. This is also a critical part to making the whole system work, as it cannot be a hinder to the scanner, and must allow at least three fluids to going from a stationary fluid line, into a rotating core holder. While it is doing this it has to withstand corrosive fluids and not mix the different fluids.

To achieve a leak-proof swivel, it will contain large about of ports, for the top swivel, which has three different fluids, it will have a total of seven ports. Three will be used for the fluids that will be transported into the core holder, Confining oil, fluid 1 and fluid 2. The other four will be used for seal oil, which will work as lubrication for the O-rings, as well as natural medium for potential leaks. The seal oil will be in a closed system and will also be monitored for pressure. An increase in pressure can indicate a leak in the swivel.

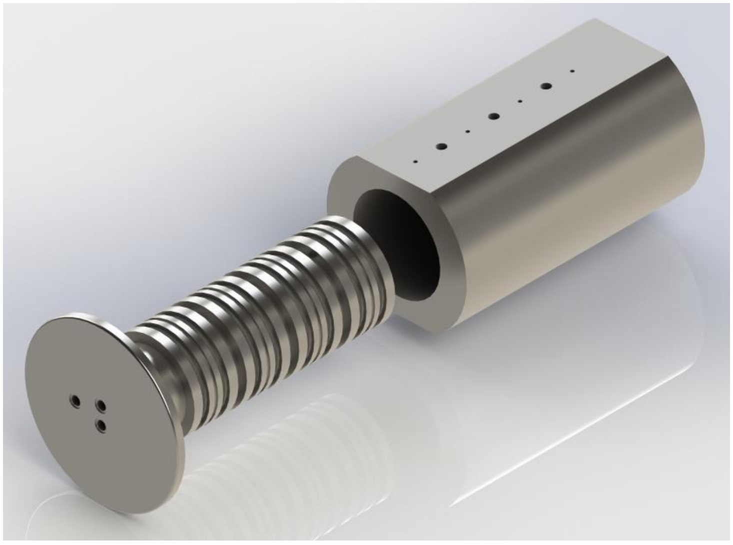

Figure 2: The swivel, with the male and the female part. There are three larger ports for the fluids and 4 smaller for the seal oil. On the male part there are lots of cut grooves, to house the O-rings, and to allow for an even flow of fluid no matter of position of the swivel.

The friction that the swivel makes in related to the amount and type of O-rings that is present, surface area, the temperature and the pressure difference between the different sections of the swivel. There is there for several solutions to minimize the friction from the swivel. The solution chosen for the design incorporates special O-rings. If this is not enough there is also the possibility to pressurize the seal oil, meaning that the pressure difference between seal oil and the fluid lines decreases and therefore will the friction decrease.

The first and easiest is to decrease the size of the swivel itself. The smaller area that is contact with the O-ring, the less friction is produced when turning. Therefor is the size important to be reduced also here. There is also the choice of various O-rings, the ones that is designed for sealing on the inner or the outer diameter. It will be a smaller surface area to use the one that seal in the inner seal, but this is unpractical as getting the O-rings in can result in a breakage of the O-Ring.

3.6 Usability and manufacturing:

The core holder will be used with corrosive fluids and under relatively high stress on parts, and therefore it is not impossible to imagine that parts will wear and eventually also break. Therefor it is always a good idea to keep things simple, but still allow it to be user friendly.

Each sample that will be analyzed will need to be placed inside the core holder and tighten up the caps. This will result in a lot of tightening and loosening of bolts. To minimize this, two collars is used to connect the core holder with the two swivels. This results in an easy and fast extraction of the core holder from the CT-scanner.

The design of each part has been kept as simple and small when possible to reduce the weight for the CT- scanner, but also to reduce the manufacture cost by advanced designs. This is important when spare parts have to be constructed. Majority of the parts can to be made in the local mechanic workshop, with the exception of high precision carbon fiber parts.

4.FURTHER DEVELOPMENTS

As there have not been too many similar setups, it means that there will be some basic studies of different material for this machine. This may be performed alongside, or directly in the experiment setup. The question is to find the best solution according to price and to longevity of the parts.

An example for test will be to expose various types of materials for the corrosive fluids and temperatures and see how they age. The use of a reactor will be used to test various fluid materials. One of the initial tests will be to test the sleeve that will support the sample inside the core holder. Example materials which will be tested, is butyl rubber, viton and the common nylon heat shrink tube. Each has different advantages, such as the heat shrink tube's ability to tighten as it is exposed to heat. O-rings are also things to be studied, though being used in a wide variety of applications, it is has not been studied at the highly saline brines that is planned to be used in the future. This means that we will have to test different types of O-rings to get the best solution, when it comes to least friction and to longest lifetime. The more favored type of O-ring is a 2 parts, PTFE and Viton rubber.

Other than testing different plastics and rubbers, there will be undergoing tests of the various parts, refining of the design as well as testing different materials. An example of further development that will occur of the mechanical parts will be to increase the resistivity against corrosion by either surface treatments or upgrading the materials used. Refining of the design might result in a user friendlier design, and a cheaper and lighter construction. Due to a limited budget, and that the design will change quickly during the initial runs, we chosen to go with cheaper materials. To start with most of the parts will be created of various types of aluminum alloy, to insure a combination lightweight and strength. The wetted parts might then be upgraded to corrosive resistive alloys, such as Monel or Hastelloy.

For obvious reasons there will not be active testing and refining of the design, but rather successively improving as parts fail or wear. But over time, especially in the beginning it is not impossible that the design will change drastically.

5. CONCLUSION

The core holder will be a crucial, but not the only part, of the core flooding CT-scanning setup. It is a setup where there will be lots of compromises to accommodate for safety, price and performance. When it comes to the core holder, will it be one of the first parts to be created, when necessary modifications has been made to the design, to be able to fit it inside the CT-scanner. The planned date for construction is summer 2014.

The initial version will be able to support a core sample with a diameter around 40mm, and a length up to 500mm. it will then allow to simulate the conditions of a rock buried at 2 km depth. This means that the core holder will able to produce a hydrostatic pressure of 200bar and elevate the temperature to 150°C. The core holder will then also, as the name suggests, be able to flood the sample with various types of fluids and gases. The fluids will range from regular waters, to highly saline brines and acids.

The sub project of the core holder will be alive throughout the whole life of core flooding projects, as it will adapt to eventual changes in the fluids, pressures, temperatures, and surrounding system. This current design of core holder will be what will be used in the initial tests, and shall provide a good starting point for further developments.

6. REFERENCES

Ott, H., et al. Core-flood Experiments for Transport of Reactive Fluids in Rocks, *Rev. Sci. Instrum.*, **83,**(2012)