READY TO ROCK

LEONHARD GANZER AND JONAS WEGNER, HOT MICROFLUIDICS GMBH, DESCRIBE HOW MICROFLUIDIC SOLUTIONS USING A ROCK-ON-A-CHIP APPROACH LOOK SET TO REVOLUTIONISE IOR/EOR PROCESS VISUALISATION.

The famous rock band, Queen, announced that they were taking on the world in their song 'We Will Rock You'. As microfluidic solutions are about to take a share of the IOR/EOR world, they are set to rock displacement process visualisation and turn IOR/EOR challenges into opportunities. Oil production is taking petroleum exploration and production into challenging areas: in particular, mature fields and

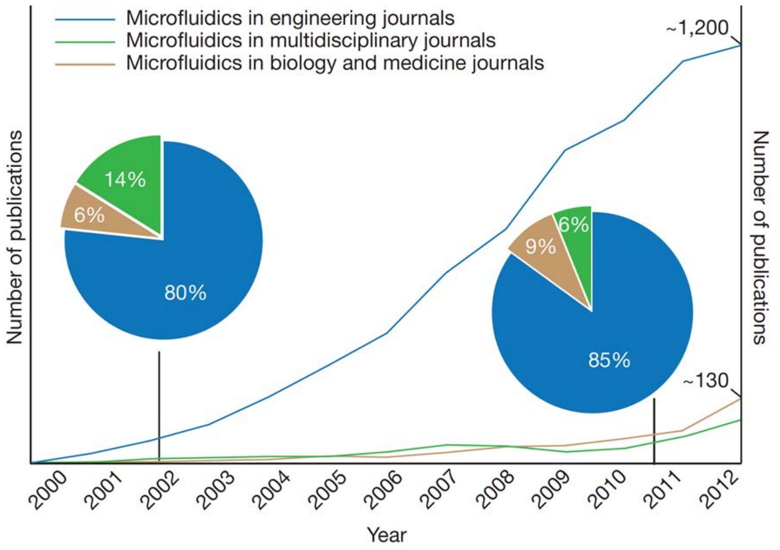

Figure 1. *Microfluidic publications in engineering, multidisciplinary, and biology and medicine journals from 2000 to 2012. (Sackmann et al, 2014).*[1]

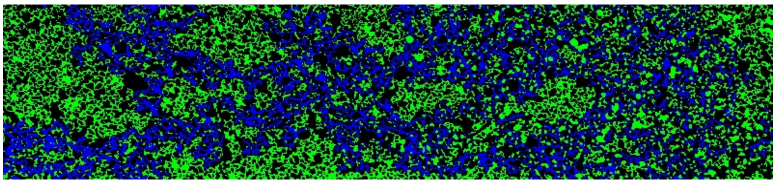

Figure 2. *Visualisation of water injection experiment using microfluidic chip designed for formation X.*

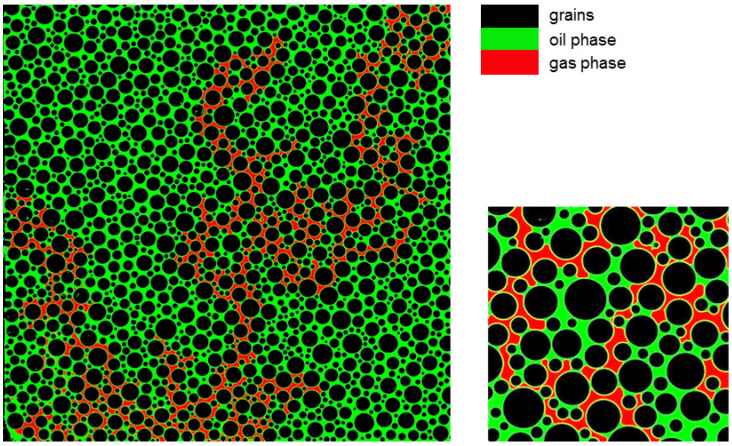

Figure 3. *Injection of immiscible gas leads to low oil recovery due to viscous fingering.*

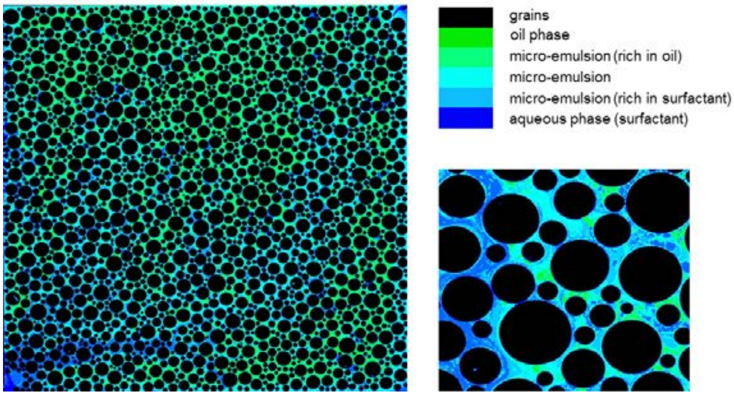

Figure 4. *Displacement of oil during surfactant flood showing mixing and emulsions.*

complex rock types pose challenges that require interdisciplinary approaches and thinking outside the box. To mobilise considerable fractions of the remaining oil in mature reservoirs requires a thorough understanding of reservoir rock and fluid properties. New and advanced technologies are required to be successful in this contest and to bridge existing knowledge gaps.

The challenge – getting to the core of IOR/EOR processes

Enhanced oil recovery (EOR) comprises various techniques to increase the amount of oil that can be extracted from an oil reservoir. Core flood experiments are the current industry standard to assess and optimise EOR processes and performance. Analysis of core floods leads to critical input parameters required to design pilot tests and field scale EOR applications. Some of the major challenges and shortcomings of these core floods are as follows:

- Shortage of representative core material.
- Replication of core results.
- Duration and costs of experiments.
- Restricted visual access.

Core displacement experiments are rather complex and time consuming. The industry has to face the challenge of having only a limited amount of reservoir rock material available to run a sufficient number of experiments as core material is expensive and sometimes even absent. Moreover, acts as a black box restricting a detailed description of static and dynamic flow properties, as the analysis is limited, mainly to global recovery and pressure. Some mechanisms, such as pore-scale displacement effects as well as complex fluid-fluid and fluid-rock interactions during IOR/EOR processes, are not completely understood when using traditional IOR/EOR techniques.

The approach – small in size, big in impact

HOT Microfluidics uses a new rock-on-a-chip approach to tackle the above-mentioned challenges. In general, microfluidics is the science and technology of manipulating and controlling fluids – usually on the millilitre scale – in networks of channels with very small dimensions (from tens to hundreds of micrometers).

Microfluidic solutions are an emerging and disruptive technology already established in various applications (including the chemical or biomedical industry), offering overall cost reduction as well as new and innovative insights. It also is a very attractive technology to investigate fluid flow through porous media as it requires only small fluid volumes (1 - 3 ml per experiment) and experiments are conducted in a short period of time (hours instead of days or weeks).

The number of microfluidic publications in journals has multiplied by ten between 2000 and 2012 (Figure 1). This is an indicator for the enormous potential of microfluidics and the respective strong market growth. In fact, the global microfluidics market is expected to exceed US$12 billion by 2025 (Transparency Market Research, 2017).[2] The technology has also been discovered for IOR/EOR applications in the oil and gas industry. HOT Microfluidics uses transparent micromodels that resemble the porous structure of reservoir rock to enhance oil recovery by providing superior IOR/EOR process visualisation.

The solution – a turnkey microfluidics flooding rig

A more precise, faster and cost-efficient solution for EOR process screening is offered by HOT Microfluidics. This new technology gives a better understanding of numerous EOR parameters, such as recovery factor and in particular pore-scale oil mobilisation and trapping mechanisms.

The standard micromodel is a sandwich of two materials: glass-silicon-glass (GSG). The porous structure to be etched onto the silicon wafers resembles the rock fabric obtained from rock samples (e.g. thin-sections, micro-CT scans), but can also be purely artificial. It is dry edged through the silicon, which results in a transparent micromodel. The rock analogs etched on silica wafers preserve the porosity and permeability of conventional oil reservoir rocks. The company's GSG Micromodel technology is superior to conventional micromodels made of silicon, glass or PDMS, because it generates chips that:

- Are transparent and hence ideal for visualisation.
- Allow for small pore throats and complex flow geometries.
- Are suitable for experiments at high pressure and temperature conditions.

Micromodel chips offer a variety of advantages: they allow cost-efficient EOR process screening as they require only small fluid volumes and reduce the number of required core floods substantially. An unlimited amount of chips with the same pore network can be produced. Micromodels are generated based on rock images, thus this technology can be applied even if physical core material is not available. They allow visual access to the displacement process enabling a more detailed process description as well as control of wettability. In microvisual experiments, image analysis substitutes for effluent material balance as performed during core floods. Flooding experiments are performed at reservoir temperature conditions and several image analysis algorithms are available to evaluate experiments including:

- Phase saturation distributions.
- Recovery factor versus time or PV injected.
- Ganglia statistics and dynamics.
- Size and extension of mixing zones.
- Streamlines and particle tracing.

HOT Microfluidics provides microfluidic IOR/EOR services and has developed a turnkey solution for providing microfluidic services including hardware and software components such as a microfluidics flooding rig (InspIOR).

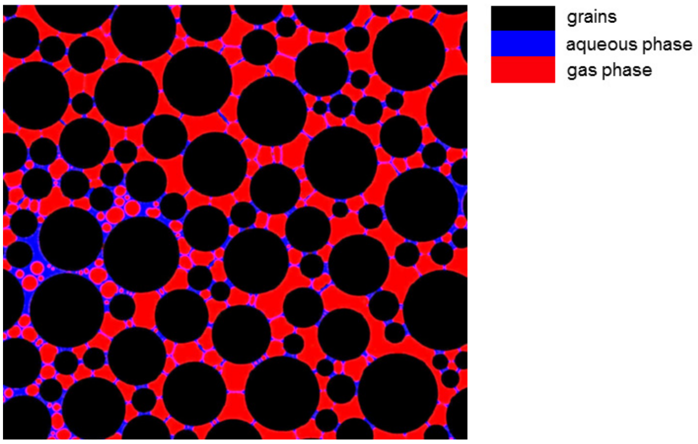

Figure 5. *Foam flooding in micromodels.*

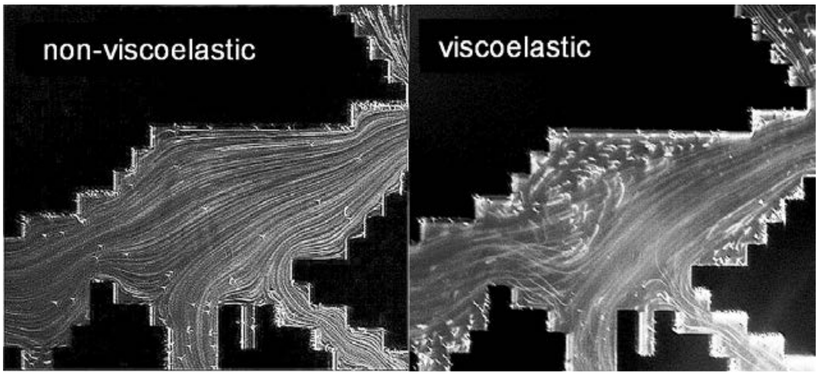

Figure 6. *Comparison of streamlines of non-viscoelastic benchmark fluid and viscoelastic polymer (showing viscoelastic turbulence(s)).*

The result – enhanced visualisation of IOR/EOR processes

The company's solutions provide enhanced capabilities for understanding IOR/EOR processes by improving process visualisation – not only recovery factor but in particular pore-scale oil ganglia trapping and mobilisation mechanisms. The rock-on-a-chip approach helps companies reduce their operating expenditures (Opex) and increase the probability of successfully implementing complex EOR field applications.

The transparent micromodels together with the experimental setup are utilised to generate high-resolution images of the flooding process. Results from displacement experiments obtained with the chips are analysed through image analysis. Image analysis represents another major difference to conventional interpretation of rock lab experiments and offers interesting aspects to report on data like recovery factor, displacement efficiency, front stability, tortuosity, break-through performance, residual oil saturation and others. The improved visualisation allows a deeper understanding of EOR processes and a more informed planning resulting in minimised risk and leveraged opportunities. Applications include, but are not limited to:

Brine flooding and mobility control processes

Micromodels are used to evaluate the efficiency of brine flooding and mobility control related EOR/IOR processes, such as polymer flooding. Figure 2 shows a subsection of a micromodel that resembles properties of a particular sandstone oil reservoir. The oil phase (green) is being displaced by brine (blue), which is injected at the left part of the chip. The process can be visualised and images are taken at high resolution. Figure 2 displays the recovery efficiency at break-through.

Gas injection

Immiscible gas injection leads to strong viscous fingering effects, resulting in low oil recovery as shown by a micromodel (Figure 3).

Miscible processes surfactant EOR

Injection of surfactants can trigger 'miscibility' between oil and aqueous phases and facilitates the formation of emulsions of different types (Figure 4 is an example). This leads to improved oil displacement efficiency. A large number of chemicals need to be tested to identify the optimum chemical formula for a specific reservoir. In addition to phase behaviour tests and core floods, microfluidics are a valuable complementary screening tool saving time and money.

Foam

Micromodels allow characterising of foam related EOR processes (bubble size, count and distribution, foam stability, etc.) at conditions. An example of foam flooding in micromodels is shown in Figure 5.

Polymer EOR and viscoelastic turbulence

Special types of polymers used for EOR exhibit viscoelastic turbulence that can lead to an improved oil recovery. Figure 6 compares the streamlines of a viscoelastic polymer and a non-viscoelastic benchmark fluid at the same injection rate. Micromodels allow investigating turbulence effects for various critical parameters such as brine salinities, polymer product, type and concentration, pressure and temperature.

Summary

Microfluidics allows for the complex design of porous structures, matching real grain morphology, pore size distribution and porosity at affordable pricing. Another important aspect in the design and construction of microfluidic chips for multi-phase fluid flow experiments is the modification of surface properties such as wettability. For instance, surface coating using nanotechnology can be used to control the wettability of the micromodel. No matter if oil-wet, mixed-wet or water-wet, any wetting pattern and contact angle can be established. Thus, wetting conditions observed in reservoir rock samples can be established in the micromodel chips.

The setup and handling of microfluidic equipment incurs low costs – experiments are repeatable due to the potentially large number of equivalent chips, require only small fluid volumes, and comprehensive visual access is provided during the experiments. Microfluidic chips can also be designed based on high-resolution rock images only, rendering the availability of rock core samples obsolete. ■

References

1. Sackmann, E. K., Fulton, A. L., & Beebe, D. J., 'The present and future role of microfluidics in biomedical research', Nature, 507(7491), 181 - 189, (2014).
2. Transparency Market Research, 'Global Microfluidics Market is Expected to Reach US$12.45 Billion by 2025: Emergence of Cost-effective and Innovative Products to Encourage Growth', retrieved from www.prnewswire.com (April 2017).
3. Ganzer, L., Wegner, J. and Buchebner, M., 'Benefits and Opportunities of a "Rock-on-a-Chip" Approach to Access New Oil', Oil Gas-European Magazine 39, p 43 - 47, (2014).