The Impact of Oil Viscosity Heterogeneity on Production Characteristics of Heavy Oil and Tar Sand(HOTS) Reservoirs

Part III: The Origin of Highly Non Linear Oil Viscosity Gradients and the Design of Geotailored Recovery Processes Suitable for such Compositionally Graded Reservoirs

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Introduction

The world oil inventory is dominated by heavy oils and tar sand (HOTS) bitumens generated almost entirely by the process of biodegradation. This process is a biologically-driven, complex reactive diffusion-dominated in-reservoir oil alteration process that occurs under anaerobic conditions (Aitken et al., 2004) driven by oil-water reactions, usually at the oil column base producing methane and heavy oil as by-products (Head et al, 2003). Because large volumes of lighter hydrocarbon components are consumed by the biological process at the oil-water contact or transition zone, significant vertical and lateral gradients in oil composition and thus oil viscosity result (Larter et al., 2003,2006a,b). The ultimate controls on the increase of oil alteration and thus viscosity rise are related to the oil charge composition and charge rate history (Adams et al., 2006), mixing of fresh and biodegraded oils and diffusion of oil components (Koopmans et al., 2002), the extent of the water leg in the reservoir and nutrient supply, and the reservoir temperature history (Larter et al., 2003; 2006a). Temperature ultimately controls the survival of microrganisms in the subsurface with reservoir pasteurisation at 80°C and above (Wilhelms et al., 2001).

Origin of Highly Curved Viscosity Gradients in HOTS Reservoirs

The defining characteristic of heavy and super heavy oilfields is large spatial variation in fluid properties, such as oil viscosity, commonly seen within the reservoirs. Viscosity can increase by up to one hundred times across a 40 m thick reservoir. Traditional heavy oil and tar sand exploration and production strategies rely significantly on characterization of key reservoir heterogeneities and assessments of fluid saturations. It is important to understand how these properties vary as the spatial distribution of fluid properties can often dominate the oil phase

mobility ratio (oil effective permeability/oil viscosity) distribution which in turn controls production behavior under cold and thermal recovery but surprisingly, in most reservoir simulations, fluid variations are often ignored! Petroleum biodegradation proceeds at the oil-water contact (OWC), or basal reaction zone under anaerobic conditions in any reservoir that has a water leg and has not been heated to temperatures over 80°C. For instance, to the west of the Peace River tar sands, near Fairview, Alberta, Cretaceous Gething reservoirs were heated to temperatures greater than 80°C and pasteurised prior to later uplift, thus these oils have undergone little or no biodegradation. In contrast, at the Peace River tar sands, which remain biologically active today, biodegradation continued, and resulted in heavily biodegraded oils. This ultimately led to preservation of essentially non-degraded oils in pasterurised Lower Cretaceous reservoirs to the west of the Peace River tar sand area, while heavily degraded oils are found in Peace River and severely degraded oils at Athabasca (Adams et al., 2006). The regional oil viscosity trends broadly also follow this pattern.

The process of biodegradation is driven from the basal reaction zone near the oil-water contact with reactive hydrocarbons brought to the reaction zone by diffusion and during field charging advection. This results in the most altered and viscous oils being located at the base of the oil column in most instances (Larter et al., 2003; 2006) which is where wells are often placed for thermal gravity drainage processes such as SAGD or CSS. We have developed several full physics numerical models of the biodegradation process (e.g. 1DRS) which couple charging and biodegradation in a reservoir simulation environment. These allow us to calculate changing compositional profiles through geological time and also predict viscosity gradients distant from well control in HOTS reservoirs. We describe why we find curved, parabolic or even exponential viscosity depth profiles in western Canadian reservoirs where oil charge has terminated(Fig 1,b,c,d, but in actively charging traps elsewhere in the world, we typically see more sub-linear viscosity versus depth profiles(Fig 1a). We also describe the dynamics of the biodegradation basal reaction zone which can be several meters thick and its impact on the production character of HOTS reservoirs. The ability to perform reactive reservoir simulations with full physical models of biodegradation allows us to populate full reservoir simulator models with mixtures of oils that fully reflect the viscosity heterogeneity of a typical western Canada HOTS reservoir. This together with advances in optimisation technology and parallel computing developments (Gates and Chakrabarty, 2006a, 2006b) applied to reservoir simulations allow automated development of advanced recovery processes that are tailored to the heterogeneities found in HOTS reservoirs. We describe two such geotailored processes we are exploring.

Geotailored Recovery Processes

As we described above, compositional and fluid property gradients are common and well documented in conventional heavy oilfields and in super heavy oil occurrences such as tar sand reservoirs. In the severely biodegraded oils of both the Athabasca and Peace River tar sand reservoirs, highly non-linear chemical compositional and fluid viscosity gradients are common and have been shown to dramatically impact existing generation recovery processes such as SAGD and CSS (Larter et al., 2006a; Adams et al., 2007). The ability to recognise these compositional gradients and import them into reservoir simulators (Larter et al., 2006a; Adams, 2007) allows design of recovery processes that take advantage of, rather than fight, these natural phenomena. We describe a new generation of transitional and initial thermal recovery processes that take advantage of the near ubiquitous viscosity and mobility ratio gradients: JAGASS and iSAGD, which demonstrate significant improvements in recovery and economics over existing thermal methods (Adams et al., 2007). Well configurations tailored to specific reservoir geometries and properties as well as fluid property distributions for primary thermal recovery increase initial

production by 50 to 100%. Substantial cost savings and overall recovery enhancement are achieved in transitional cold primary to thermal secondary recovery methods (JAGASS) by using a production J-well placed below what is initially a cold production well, which is then later used to inject steam as in SAGD. Detailed 3D reservoir simulations predict roughly 25% more oil recovery with about 50% drop in cumulative steam-oil ratio compared to standard SAGD in an identical reservoir. The JAGASS process has many similarities to SAGD such as steam trap control and potential for low pressure and solvent-assisted operation. We outline how we think future thermal recovery processes will evolve to cope with western Canada's hetergenous reservoirs and their heterogenous fluids.and we describe our combined fluids, rock and simulation approach to reservoir characterisation and recovery process design.

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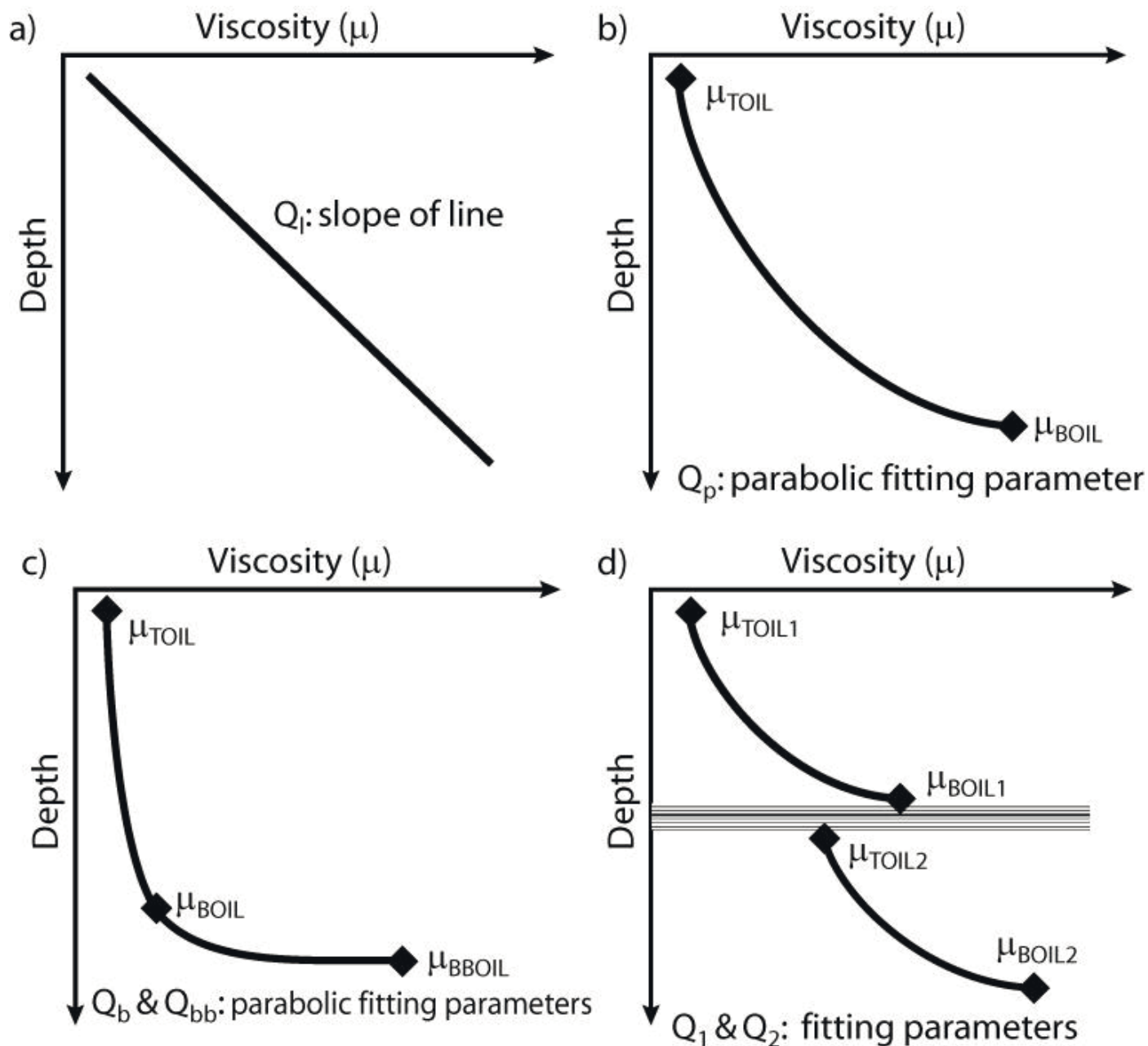
Figure 1. Viscosity gradients seen in HOTS reservoirs. 1A-sublinear gradients are common in actively charging basins, whereas highly non linear depth viscosity gradent profiles(1,b,c,d) are seen in basins such as the WCSB where oil charging ceased a long time ago. In compartmentalised reservoirs, such as in 1d, complex mutliple stacked profiles are also found related to separate compartment charging and biodegradation events. To accurately define the profiles it is important to sample and measure fluid properties at sufficient resolution.