

Reply's to Reviewer 1

We welcome the points raised by the Reviewer #1 which advise us: *"A major revision was required before the next step.*

1. Although the test bench has been introduced in the previous papers, important parts, as well as the main steps and conditions, still need be presented.

Reply: Done, along the introduction and in other parts we added important details related to the experiments and its relation with the actual SAGD process and the theoretical model. Thus, after the second paragraph on page 2 we write:

"We need highlight, based on field trials, that the steam chamber shape evolves slowly in the time [17]. In our theoretical model [10] the (hypothetically instantaneous) knowledge of the shape of chamber it is necessary in the quantitative determination of the optimal injected mass flow rate of steam; this is the fundamental assumption in the proposal for the use of a preformed chamber in the experiments. Since a theoretical point of view, the solution of the steam condensation problem at the chamber edge (of a given form), which must be computed numerically, turns out to be physically admissible only for a particular value of ϕ_{opt} , that depends on a set of dimensionless parameters."

Similarly, in the new fifth paragraph on page 2 we clarify how the steam chamber achieves the saturation of steam and the importance of the initial saturation in some heterogeneous reservoirs, where SAGD is inefficient, for instance, due to lean zones. Such a paragraph says:

"We will notice that in each of our ideal injection experiments, the chamber is initially dry, i.e., there is not any initial water saturation and, eventually, a steam-saturated stage will be reached. However, the SAGD process is sensitive to the heterogeneity of oil sand formation, as has been detected due to the presence of lean zones during the steam injection [19–21]. The lean zone is a zone in which water saturation is higher than 40%. The lean zone can be found in reservoirs as bottom water, top water, or pockets of water at different elevations and behaves as a thief zone during SAGD production. Field-scale studies show that a well pair is most affected by lean zones above its injector, than the other cases. The high heat capacity of water, which is almost twice that of oil, when combined with high water saturation, leads to high steam demand when steam intercepts lean zones. Due to it, the steam-oil ratio (SOR) increases and decreases oil production. When these inhomogeneities are absent the SAGD technique is generally efficient, with steam-oil ratios in the 2 to 5 range, which means SAGD generally requires converting between two to five barrels of water into steam for the recovery of one barrel of crude oil. The pressure of the lean zone is another parameter that influences SOR and bitumen rate during SAGD operation. Lean bitumen at low pressure (lower than 1000 kPa) may require a large volume of steam to increase the pressure to that of SAGD operation pressure."

We detailed in the paragraph previous to subsection 2.2 that the preformed elliptic chambers have the same size and the circular one is such that it can be inscribed in the ellipses:

“As is shown in Fig. 1, the areas of the ellipses are the same $A_e = \pi ab = 0.052 \text{ m}^2$ and the area of the small circumference is $A_c = \pi R^2 = 0.031 \text{ m}^2$, which means that the area of the circumference is around $0.6A_e$, our criterion for choice the size of the circumference was that it could be inscribed in the ellipse.”

In Section 3, as a first paragraph, we added a comment on the well constraints in our experiments and in actual SAGD:

“The wells constraints in experiments were that, along the injection pipe, steam is injected radially into the porous medium at pressure p_i and in the recovery pipe, the condensates, and eventually the steam, outflow. In terms of the pressure, the lower end of the chamber is close to the production pipe, and during injection the pressure in the chamber decreases to about the pressure in the production pipe, which is the ambient pressure (in an actual reservoir such a pressure is not very different from that of the reservoir [24]). In this stage, the spatial pressure variations in the steam chamber are small compared with the hydrostatic pressure variation in a distance of the order of the height of the steam chamber. However, the small spatial pressure variations determine the flow of steam in the chamber and the distribution of condensation flux at its boundary.”

2. The experimental results are listed without in-depth analysis.

Reply: We believe that our main experimental results have in-depth analysis because additional to the determination of the existence of the optimal injections, which we show that depend on the steam chamber shapes, as has been predicted through our formal fluid mechanics model [10], we measured experimentally the transient condensate fronts reaching the chamber edges, and to understand it we alluded to other theoretical study on radial hot water injection [28], to fit different power laws of time to data. In these last cases, we also discuss how such fronts interact capillary with the solid boundary due to the water wetting. We commented that if water does not wet the steam chamber edge, an emulsion can be produced. The stability of this film, close to the high-viscosity oil region, could depend on the effective gravity and the local curvature of each chamber shape. This last is an open problem. We added this paragraph at the end of Section 4:

“We also believe that the local curvature of each steam chamber used in experiments may influence the downward flow intensity, through the effective gravity. Consequently, more careful studies correlating gravity and both types of liquid films will be performed in order to complement our experiments in preformed steam chambers.”

3. The comparison of the results with different steam chambers should be analyzed in detail.

Reply: Done. The pertinent arguments are similar to those given in the previous question.

4. The motivation and innovation need to be further summarized.

Reply: Done. In the improved Introduction and in the improved Conclusions we mentioned that our motivation for this study is that the knowledge of the instantaneous shape of the steam chamber, of the parameters of the reservoir and of the involved fluids, may help to improve the crude oil production in homogeneous reservoirs.

As innovations we express that inhomogeneities (lean zones) in the reservoir and technical procedures as subcool may be imposed in the experimental set-up in order to observe, and measure, the impact of such situations on the performance of the condensate recovery in our steam chambers. Close to the end of the Conclusions we added the following phrase:

“We need comment that in actual field operations subcool is one of the keys for stable SAGD production due to forming a certain height of steam-liquid level to prevent steam breakthrough and improve the utilization efficiency of heat. However, the location of steam-liquid level can’t be monitored in field operation, and can only be approximately adjusted by monitoring and maintaining reasonable injection-production temperature difference [36,37]. Finally, in our current experiments we did not find these situations, but in future studies we could establish them in order to measure in a controlled manner their effects.”