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Application of Stream Conversion Methods to Generate Compositional Streams From the Results of a Multi-Million Cell Black Oil Simulation Study of the Shaybah Field

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Abstract

Detailed compositional simulation of a giant reservoir with many components is not practical. However, detailed multi-million cell black oil simulation of giant reservoirs is now quite feasible. In this work we apply an efficient method to generate the compositional rates from a black oil simulation of the giant Shaybah field.

In situations where the reservoir recovery mechanism is not dominated by compositional effects, an Equation of State (EOS) based stream conversion method can be used. This stream conversion method relies on the fact that when laboratory PVT data measured on available well stream compositions are used to generate the black oil PVT tables, some of the compositional information is lost. The stream conversion model retains this valuable compositional information and applies it to each producing well completion in the black oil simulation at every time step.

As proof of concept, the stream conversion method was applied to a black oil simulation and to a limited (eight-component) compositional simulation to generate a 17-component compositional stream and the results were compared to the respective full EOS compositional simulation for a relatively small sector (250,000 cells) of the giant Shaybah field. The compositional stream rates are in excellent agreement with the stream converted black oil results. As would be expected, the computational costs of using the EOS based compositional simulator (with 17 components) is in excess of 40 times the black oil simulation time for the small sector model. In general, the stream conversion method can be used to generate the dynamically varying compositional streams from any black oil simulation for use in the design and operation of surface facilities and in calculating the amounts of a certain cut (e.g. NGL) from the production streams.

Introduction

Recent advances in parallel reservoir simulation technology[1] has made it feasible for modeling the performance of giant hydrocarbon reservoirs using simulation models that retain the full geologic model resolution[2,3,4,5]. These multi-million cell simulation/geologic models when carefully conditioned to engineering data, lend themselves to rapid history match contrary to its size[2,3,4]. More importantly they are actively used in optimizing field development with more confidence and in day to day reservoir management[3,4].

The above mentioned multi-million cell simulation models use a black oil treatment of the hydrocarbon fluids. Where compositional treatment of the hydrocarbon fluids is desired, a conventional full Equation-of-State (EOS) based compositional simulation of a giant hydrocarbon reservoir with many components is not yet practical. In this work we apply an efficient method[6, 7] to generate the compositional rates from a black oil simulation of the giant Shaybah field. The theoretical basis for this method is presented in detail in Reference 7. Herein we present only the pertinent information to elucidate its application in this work.

Stream Conversion Methods

Stream conversion method as the name suggests, is used to convert data from one form to another. Although the application of this method is general, here we apply this method to petroleum streams and more specifically to the conversion of surface volumetric rates of oil and gas from the black oil simulator into overall compositional rates for the desired number of components.

A full EOS fluid characterization is performed using all the laboratory PVT data that preferably covers the full operating range of pressures and compositions. This EOS is used to generate the black oil PVT tables and the Conversion Factors (split factors) from depletion experiments covering the whole operating pressure range in the reservoir with a high frequency of pressure points.

The conversion factors are used to convert the volumetric surface oil and gas rates from the black oil reservoir simulator into overall compositional stream rates at the desired number of components. The maximum number of components is usually equal to or less than the most detailed number of components in the fluid characterization.

The Black Oil reservoir simulation is run as usual but with the output of well completion rates (layer rates) for oil, gas and water and completion grid cell pressure at the frequency of the reporting interval which is usually once a month. The Streams Conversion software[8] is then used to generate the compositional stream rates for each well completion as a function of time.

This process is almost equivalent to performing an EOS based compositional simulation at each production well completion. Except that the actual simulation model is a black oil simulation and hence is very fast and the simulation model can retain the full geologic resolution. This approach is suitable for reservoirs where the recovery mechanism is not dominated by compositional effects. And in situations where the latter is the case[9,10], this approach can be applied to a compositional simulation with a limited number of components and the stream conversion method can be applied to convert the results into an extended number of components for use in facilities design or to maximize the recovery of a certain cut of the compositional stream, for example NGL.

A common thread in this stream conversion process is consistency and accuracy. The hydrocarbon fluids from the reservoir go through a series of ‘conversions’. First the reservoir simulator, say for example a black oil simulator utilizes the ‘converted’ laboratory data to black oil tables and generates the surface production rates. The surface oil and gas rates are again ‘converted’ to compositional rates for process engineering and the outlet streams from the surface facilities are again ‘converted’ to quantities that is familiar such as crude grade and the oil tanker manifest items. If a single stream conversion method is used at all these steps, then all of the ‘conversions’ become consistent and accurate. Thus as a routine it is recommended to use the stream conversion method for all black oil simulation results to convert to compositional streams for surface process engineering and other applications.

Shaybah Field

The Shaybah field was discovered in 1968 and is located in the southeastern part of Saudi Arabia. It is a large carbonate field with several billion barrels of oil-in-place and several trillion standard cubic feet of free gas. The oil in the Shu’aiba reservoir is overlain by a huge gas cap which is the primary drive mechanism. Due to the existence of this large gas cap and the rock variations in Shu’aiba reservoir, gas coning problems are expected. Oil production started in mid 1998 at 500,000 barrels per day. About 85 percent of the produced gas is being recycled into the gas cap. A simulation model (with a black oil fluid characterization) at full geologic model resolution was built resulting in 3.5 million grid cells. A 3-D view of the Shaybah simulation model is shown in Figure 1. The historical field performance was matched and a comprehensive evaluation of alternative gas production forecast scenarios and its impact on sweep efficiency and ultimate economic oil recovery was carried out using our In-house parallel reservoir simulator[1]. For evaluating the long term effects of gas cycling and surface process engineering/design and other optimizations a compositional simulation of the field is desired. But as a full field EOS based compositional simulation is not yet practical, the stream conversion method to convert the black oil simulation results into compositional results is being evaluated.

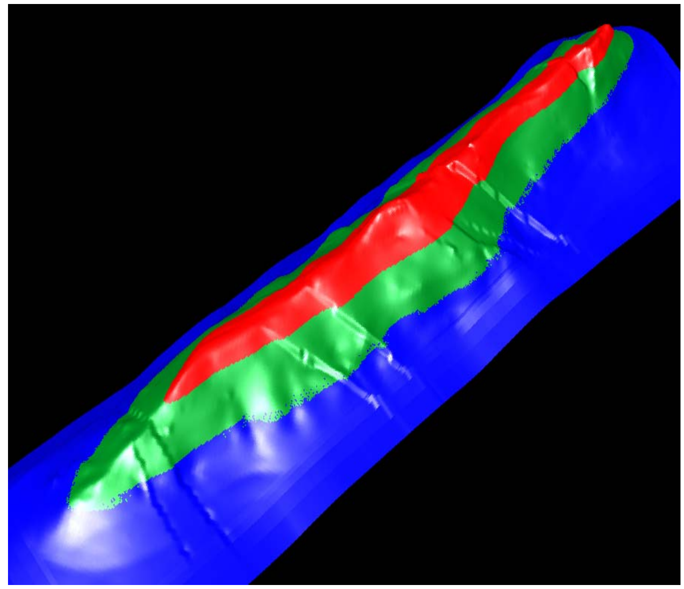

Figure 1. A 3-D view of the Shaybah Field Simulation Model

Shaybah Sector Model

Prior to applying the stream conversion method for the full field, this approach was evaluated using a relatively small (250,000 grid cells) sector model (Sabkhah 10) in the Shu’aiba reservoir. The Sabkhah 10 area is in the North West part of the Shaybah field. A 3-D view of the 250,000 grid cell simulation model is shown in Figure 2. This sector model was chosen so that a full compositional simulation could be performed and

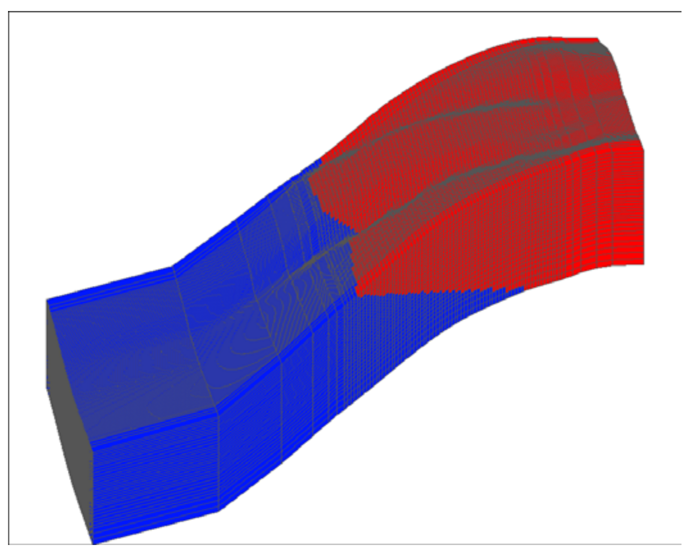

Figure 2. A 3-D view of the Sector Model (Sabkhah 10)

then compared with the black oil converted compositional results.

An EOS fluid characterization was performed using laboratory data resulting in a 17 component characterization. The list of the 17 components and eight components used in the limited compositional simulations are given in Table 1.

17 Component Names	8 Component Names
N_2	C_1N_2
CO_2	C_2CO_2
H_2S	H_2S
C_1	C_3C_4
C_2	C_5C_6
C_3	C_7C_8
IC_4	C_9C_{11}
NC_4	$C_{12}+$
IC_5	
NC_5	
C_6	
C_7	
C_8	
C_9	
C_{10}	
C_{11}	
$C_{12}+$	

Table 1. Components used in compositional simulations

In order to evaluate the extension of a limited compositional simulation using the stream conversion method, the 17 component fluid characterization was pseudoized to eight components.

The black oil PVT tables were generated from the 17 component fluid characterization. This same EOS fluid characterization was also used in the Streams program to generate the split factor tables.

Sector Model Compositional Simulations

The sector model simulations were run for 6.5 years, which included a 1.5 year historical field performance period and a five year forecast period. Two compositional simulation runs were made. In the first simulation run the hydrocarbon fluid was represented with 17 components. In the second simulation the hydrocarbon fluid was represented with eight components.

Sector Model Black Oil Simulation

As noted above, the black oil PVT tables were generated from the 17 component fluid characterization. The black simulation of the Sabkhah-10 model was run for the same simulation period as the compositional simulations. However, the run time for the black oil model is about 40 times faster than the 17 component compositional model. The Streams program was used to convert the surface oil and gas volumetric rates of each well completion into a 17 component compositional rate.

Comparison of Compositional Stream Rates

We now compare the EOS compositional simulation rates for a typical well (WELL A) in the Sabkhah-10 area with the compositional rates from converting the black oil simulation results. Figure 3 shows a comparison of the non-hydrocarbon component rates namely, N_2, CO_2 and H_2S versus time. In all the comparison figures, the symbols represent values from the EOS 17 component compositional simulation (EOS17) and the solid lines represent values from the stream converted black oil simulation (BO-17CMP).

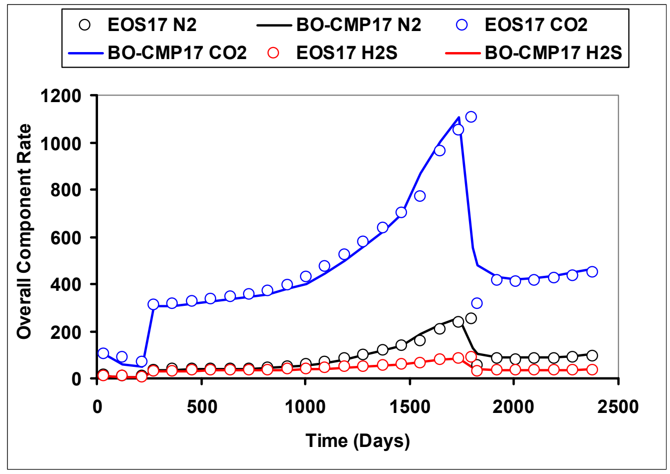

Figure 3. Comparison of non-hydrocarbon rates

We notice that the stream converted black oil results are in excellent agreement with the results from the compositional simulation for these relatively small amounts of the non-hydrocarbon components.

In Figure 4 we present the comparisons for the lighter components namely, Methane (C1), Ethane (C2) and Propane(C3) rates.

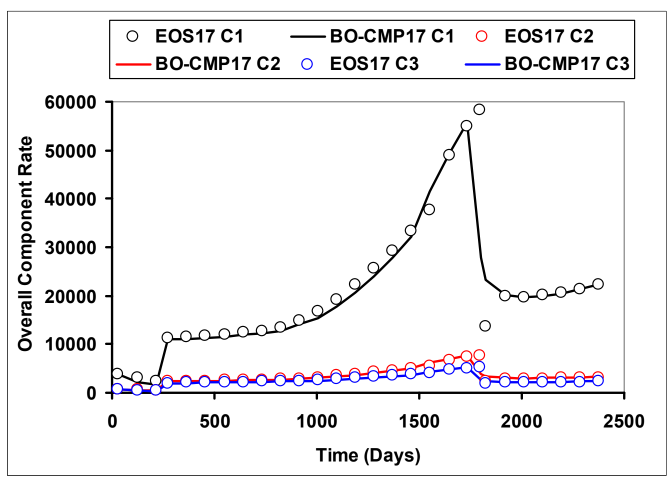

Figure 4. Comparison of the lighter hydrocarbon rates.

All the components are being tracked accurately by the stream converted black oil simulation.

In Figure 5 we present the comparisons for the intermediate component rates namely, n-butane (nC4), iso-butane (iC4), n-pentane (nC5) and iso-pentane (iC5).

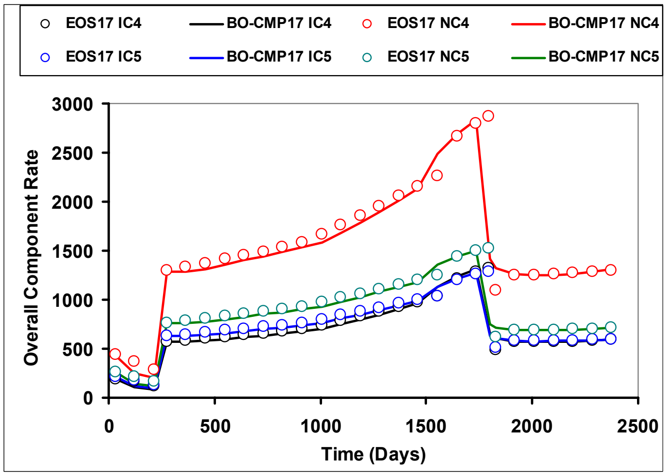

Figure 5. Comparison of the intermediate hydrocarbon rates

The agreement between the EOS and the stream converted results is excellent.

In Figure 6, we present the comparisons for the hexanes, heptanes, octanes and nonanes.

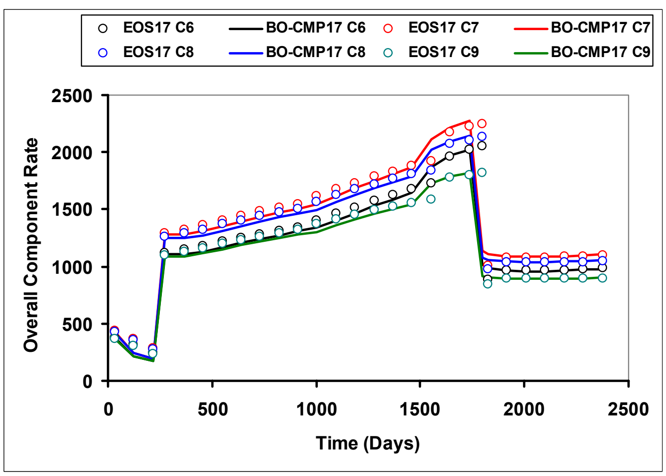

Figure 6. Comparison of C6-C9 hydrocarbon rates

The agreement continues to be very good for these components.

In Figure 7, we present the results for the heavy components n-decane (C10), undecane (C11) and the lumped C12+ component.

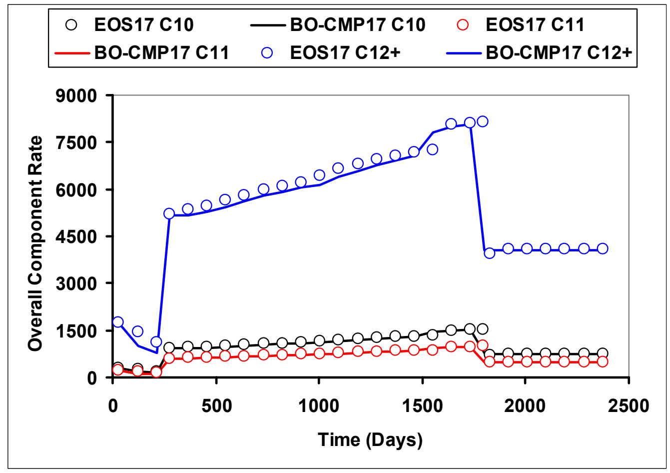

Figure 7. Comparison of the heavy hydrocarbon rates

For all the components, the streams converted black oil results are in excellent agreement with the results from the compositional simulation. One of the key reasons is that the black oil rates at the well-completion level are used[7]. Since the rates of all the components are in excellent agreement, any surface processed component rates should also be in very good agreement as the rates will be processed through the same separator stages for both compositional and black oil simulation results.

Comparison for Limited Component EOS Simulation

In cases where compositional effects dominate the recovery mechanism, a limited component compositional simulation can be performed. The results from this simulation can be extended to detailed compositional rates. We illustrate this process by running an eight component fluid characterized compositional simulation of the Sabkhah-10 area. The Streams software is then used to convert the component rates at each well completion to a detailed 17 component output. The results are presented for a typical well (WELL B) in the Sabkhah-10 area in Figures 8 through 12. In these figures, the symbols represent the component rates from the 17 component EOS (EOS17) compositional simulation. The solid lines represent the component rates from the eight component EOS (EOS8 – CMP 17) compositional simulation converted by the streams method into 17 components. In Figure 8, we present the comparison for the non-hydrocarbons, N_2, CO_2 and H_2S which make up about 1.14 mole percent of the initial overall composition.

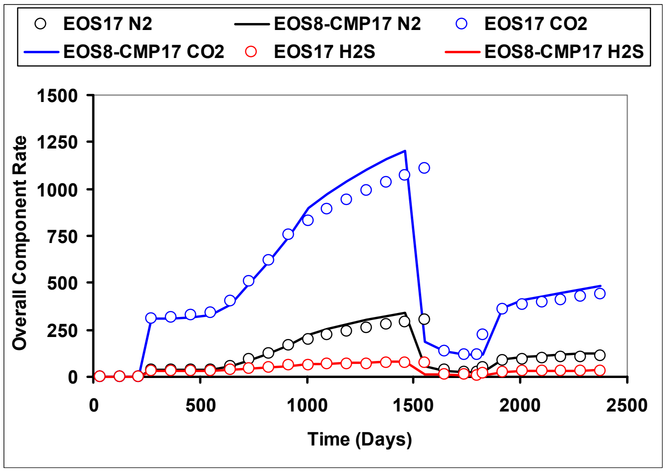

Figure 8. Limited compositional to 17 component – non hydrocarbons

In Figure 9, we present the results for the light hydrocarbon components, Methane, Ethane and Propane which makeup about 50 mole percent of the initial overall composition.

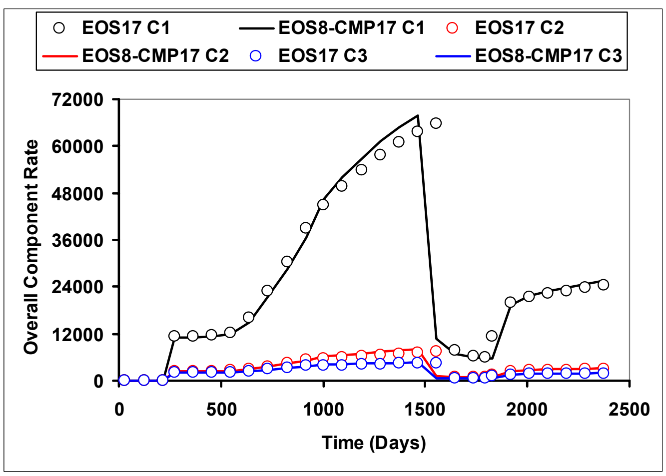

Figure 9. Limited compositional to 17 component – C1 to C3

In Figure 10, we present the comparison results for C4s and C5s which make up about 10 mole percent of the initial overall composition.

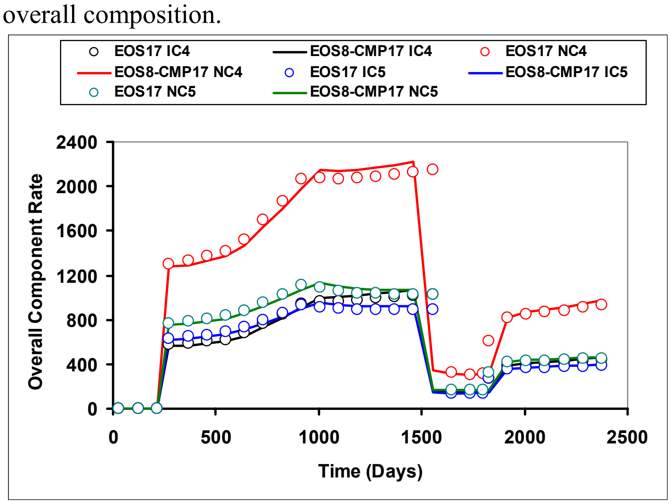

Figure 10. Limited compositional to 17 component – C4s & C5s

In Figure 11, we present the results for the Hexanes through Nonanes and these make up about 15.5 mole percent of the initial overall composition.

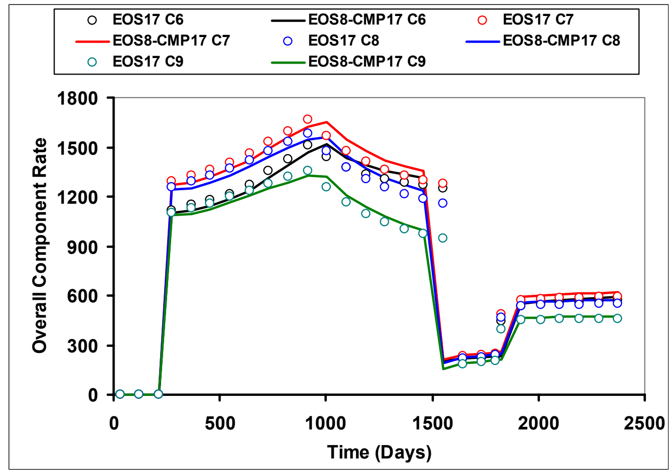

Figure 11. Limited compositional to 17 component – C6 to C9

In Figure 12, we present the comparison for the heavy components C10 through C12+ and these components make up about 22 mole percent of the initial overall composition.

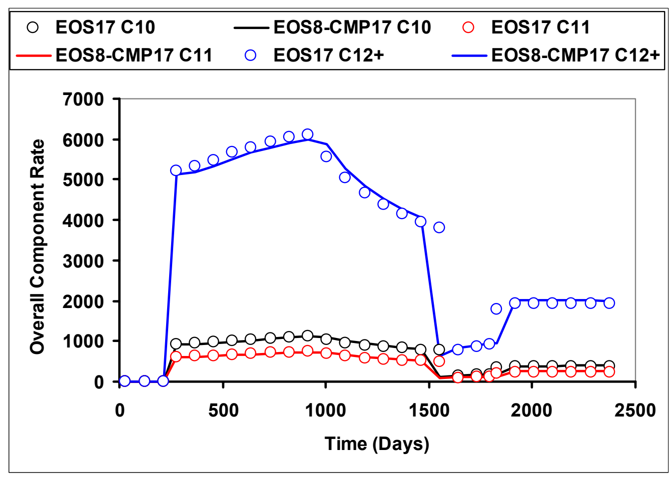

Figure 12. Limited compositional to 17 component – C10 to C12+

The good agreement in the component rates indicates that this approach can be used for situations where the compositional effects dominate the recovery mechanism. The EOS Compositional simulation can be carried out using four or five pseudo components and the results can be converted (at each well-completion) using the stream conversion method to the desired number of components for subsequent processing.

Shaybah Full Field Black Oil Simulation Conversion

In a previous section we presented a satisfactory comparison of the EOS based compositional simulation results with the stream converted black oil results (Figures 3 to 7) for a relatively small (250,000 grid cells) sector model. Prior to this work, as stated in a previous section, a comprehensive black oil simulation study of the full Shaybah field was completed using a 3.5 million cell simulation model. One of the optimized cases was re-run invoking the option to output well completion (layer) rates and the completion grid cell pressures (obviously there is no need to re-run the black-oil simulation, if these quantities were output during the original run). The stream conversion method was then used to generate the compositional streams for the entire simulation period (1998 to 2042). In Figure 13, we present the normalized component production rates for one of the Gas-Oil Separation Plant (GOSP) feed stream in the Shaybah field.

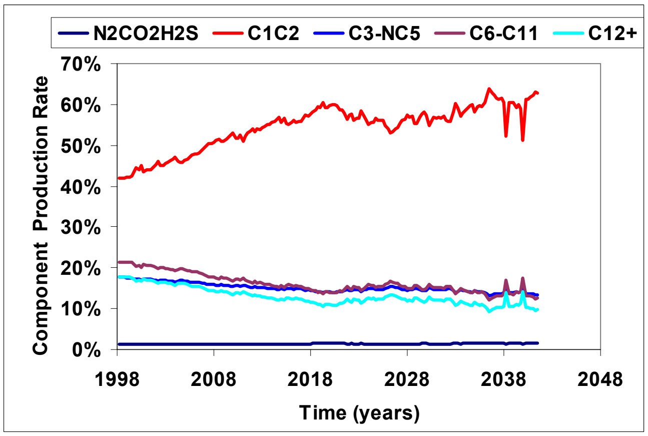

Figure 13. Normalized Shaybah GOSP component rates

For the sake of brevity, the individual component rates are lumped into non hydrocarbons, light components, intermediate components, C6 to C11 components and C12+ components.

The only additional time required to calculate the individual component rates is the time taken by the streams software to convert the black oil well completion stream rates. This process takes only a few minutes for the several hundred wells in the Shaybah field.

Summary & Conclusions

In this work we apply an efficient method to generate compositional results from a multi-million cell black oil simulation of the giant Shaybah field.

The following conclusions can be drawn from this study:

1. Application of the streams conversion method to the black oil simulation results of the 250,000 cell sector model to generate the component rates produces accurate results.
2. The rate of each of the 17 components tracks the values from a full 17 component EOS compositional simulation.
3. The streams calculated rate amounts seem to be tracked independent of their intrinsic amounts. That is, the relatively small amounts are also tracked accurately.
4. For situations where compositional effects may be important, the streams conversion method applies equally well as illustrated in the eight component EOS simulation of the sector model and subsequent conversion to 17 components.
5. One of the key reasons for the success of this method is its application at the well completion stream level. This process is almost equivalent to performing an EOS based compositional simulation at each production well completion but without actually performing a compositional simulation.
6. As expected this approach to generating the component rates is very efficient. In the case of the sector model, the black oil simulation run is about 40 times faster than the 17 component EOS compositional simulation.
7. After a successful test of the streams method to the sector model, this approach was used in the full field Shaybah model. Component rates was generated for all the 17 components from the 3.5 million grid cell black oil simulation results for a forty year forecast period with very little additional run time than the black oil simulation run.

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