

Modeling of Phase Behavior in the Evaluation and Matching of Enhanced Oil Recovery Processes by *In Situ* Combustion*

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Abstract

Enhanced oil recovery processes have taken a great boom in recent years due to the decline of conventional reserves. One of these methods with great potential application is the air injection or *in situ* combustion (ISC). There are complexities in the development of this method; however, using numerical simulation it is possible to find configurations that lead to technical and economic success.

The success of the numerical simulation is associated with the development of good phase behavior models, which could be considered the first step in the modeling of ISC process. This must be able to represent the behavior of the fluid at the conditions that will be subjected. For the development, PVT tests are necessary: constant composition expansion, differential liberation and separator tests. With these, it is possible to match the equation of state and behavior of the different phases. For this setting, it needs to identify which parameters can help to adequately represent the behavior of fluids.

A key aspect in the development of the model is the number of pseudo components to represent and how they are lumping, using the least amount of material possible without loss of the representativeness of the fluid, due to high computation times that this implies in simulation models. Once identified, we evaluate whether they represent the characteristics of the fluid, if they vary greatly, proceed to match each property, using specialized software for modeling and matching. The main tuning parameters are the critical properties of the pseudo components, acentric factor and the volume shift.

Matched phase behavior model, this can be used in laboratory-scale tests models: combustion tube (CTO), Ramped Temperature Oxidation (RTO), or field-scale model. In this case, the successful development of the reactions involved in the kinetic model for *in situ* combustion process is linked the fluid model and the molecular weight of the pseudocomponents. It aims to develop a workflow that allows obtaining a phase behavior model adequately for representing the crude behavior under different conditions of temperature, pressure and composition, resulting from the *in situ* combustion.

Introduction

Numerical simulation is a useful tool in studying the performance of an enhanced oil recovery technique. In the case of an air injection process, where the process is difficult to represent from physical scale models, since it is tedious, complicated and involves different mechanisms present in the process, further gains importance using this technique. For the proper development of a simulation model, it is necessary to properly characterize the fluid to represent, taking account of the tests on this.

Once developed, the phase behavior model proceeds to generate the model of reactions, using an appropriate number to represent most possible processes involved in the combustion process. To load the kinetic parameters, data reported in the literature are initially used and then the model fit is achieved. The reactions model leads to the development of the process simulation by setting the injection-production schedule and operating conditions, to evaluate the performance of the process in the conceptual model. A more accurate assessment requires a prior adjustment of the evidence, and this is achieved by identifying fully that which will help the simulation model accurately represents what happened in the lab.

Introduction

The *in situ* combustion process is a conventional "thermal" which is based on the generation of heat in the reservoir to continue recovering hydrocarbon production after completion primary and/or secondary. This approach involves burning 10% of the oil in the reservoir to generate heat. Generally, the process starts down a heater or burner in the injection well, then air is injected into the well bottom and starts the heater to achieve ignition. Then, the surrounding wellbore is heated, the heater is removed and the air injection continues to maintain the advancement of the combustion front ([Figure 1](#)).

A complex process such as *in situ* combustion requires a careful and detailed study of all the effects and phenomena that occur during development. Therefore, in the laboratory are several tools and parameters had to establish some parameters and the relationship between them, so that allows having a clearer idea of the process behavior. Techniques can generally be classified as quantitative and qualitative. The information obtained from these techniques is of great importance as the amount of available fuel and air requirements, vital to the technical and economic evaluation of the process. For example, we will take into account two quantitative tests: combustion tube tests (CTO) and the evidence Ramped Temperature Oxidation (RTO).

Combustion tube tests allow a representation of the behavior of a combustion process in the reservoir. In itself, this represents the flow or combustion front propagation. This type of evidence is not scalable, i.e., it may go directly to field case, but if they give an indication of the process behavior. The stoichiometry of the reactions in a combustion test tube will be the same as that of the reservoir.

In the case of the RTO, sometimes called the effluent gas analysis (EGA), we study the oxidation behavior of the reaction kinetics of a fluid-rock system under controlled conditions.

Simulation of *in situ* Combustion

The numerical simulation has become one of the best tools in studying the feasibility of many enhanced recovery. *In situ* combustion is not immune to this, as being a complex process considerably, direct application to field or a pilot is only possible when there is some level of certainty in laboratory studies (RTO tests, CTO, etc) or in the numerical simulation of the process. Adequate representation of this process using numerical simulation is associated mainly two aspects: development of a suitable fluid model and the kinetic model of the process include the reactions and the kinetic parameters of this. The phase behavior model is developed from PVT tests conducted to the fluid. With this information fits the experimental behavior subsequently simulated to develop the model reactions.

Phase Behavior Model

The successful simulation of an *in situ* combustion process is closely tied to the development of the phase behavior model, since this is the basis for obtaining a kinetic model to represent not only suitable for the reactions occurring during the process, but other mechanisms also present therein. Using the information obtained from the PVT test, and using the appropriate software company, it proceeds to describe the development of the fluid model. Once visualized or reactions are occurring in the process, it is necessary to characterize the fluid, i.e. the components are engaged in their development. Once the fluid was characterized, it is necessary to adjust the properties of each of the components using an equation of state. The data are obtained from PVT tests such as differential liberation or constant composition expansion (CCE and DL) and separator tests. It is also necessary for the adjustment, be a function of viscosity in terms of pressure and temperature.

Initially, tests identify the number of components and the mole fraction for each of these, in the case of the fluid in question will have 40 components, from C1 to C36 +, more CO₂ and N₂ components. Once done, the first thing to set is the saturation pressure of the fluid; this matching is possible by modifying the critical properties and acentric factor of component that is uncertain, the C36 + for this case. Now the idea is to represent crude pseudocomponents according to five are CO₂, N₂, C1-C5, C6-C20 and C21-C36 +. When this lumping is done, we must verify that the value of saturation pressure has not become dislodged. Therefore, the simulation is performed and shows the value of saturation pressure. If the value is equal to the experimental value, it means that the grouping was properly adjusted, but it is necessary to regress that would achieve the adjustment. Selecting pseudocomponents groups can be made as a function of distillation tests or from the values K-value that shed fluid characterizations.

When we matched the value of saturation pressure, is necessary to match the properties obtained from the PVT test, in this case has a differential release, although few data, a test at constant volume expansion (CCE) and a viscosity test. The data are obtained from the tests conducted to study fluid field. It begins by loading the test data for differential release, these data are: oil volume factor, gas specific gravity and GOR oil and three pressure levels. Subsequently, a load test separator helps matching the behavior of Rs (solution gas) and API crude. A test is also charged CCE to achieve adjusting the density of oil and oil relative volume (ROV). [Figure 2](#) shows the matching for oil viscosity.

1. Set oil composition
2. Identification of the tests and experimental properties
3. Load to suitable simulator

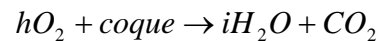
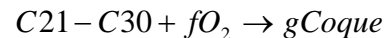
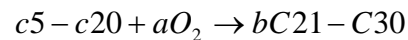
4. Evaluate the initial fluid behavior in terms of its components
5. Match saturation pressure all components having
6. Lumped into a number of defined pseudocomponents established by any of the above criteria
7. Check and match the saturation pressure once grouped components
8. Match PVT behavior and properties
9. Set the behavior of the viscosity

Simulation Model

Initially, we must define the type of model to use, in this case use a Cartesian concept to show the validity of the model developed fluid. Are loaded into the model all rock and fluid properties also conceptually. [Figure 3](#) illustrates the model used for this case. Once created, the model must verify all properties.

After reviewing the behavior of the fluid and noting that fit correctly, we proceed to add the reactions to be developed during the combustion process. Be used for this case two addition reactions or low temperature (LTO) a pyrolysis or cracking (intermediate temperature ITO) and a high temperature reaction or bond scission (HTO). These reactions are stated above and it is clear that in their formulation, they must be developed in terms of the same pseudocomponents in which fluid was characterized.

Before adding the reactions, it is necessary to verify whether the model already has all the components, both reactants and products, if something is missing, you must add and define the phase to which they belong. You can also define which phases are to be burned during the process, being here the two heavier fractions of hydrocarbons. The reactions that were raised in this case are:



Where a, b, d, e, f, g, h, I are the stoichiometric coefficients previously calculated.

Once loaded, the reactions and all parameters must be verified are not misaligned PVT properties, as when handling the components of the reactions, they may experience a slight mismatch in their values. These abnormalities are corrected, checking surface conditions and site that is taking the model.

So here was properly both the fluid model as the model reactions. Now we proceed to test them using a simulation model cylindrical that represents a combustion test tube. Like the Cartesian that was used to load the fluid model, the cylindrical model is loaded with all the properties, then imported fluid model, and then added reactions. Finally, the model is set to different events develop over the simulation stage, the most relevant being:

- It uses an injector and producer well
- Initial stage of inert gas (nitrogen)
- Injection rate adjusted periodically (descending rises at the end and then close)
- Matching the injection pressure constraint
- Step normal air injection

It only remains to test the model and to determine whether or not being effective to render the combustion process. In the simulation model are also located some thermocouples that monitor the progress of the combustion front. [Figure 4](#), [Figure 5](#), and [Figure 6](#) show the behavior of gases, temperature profiles and the produced fluids.

Conclusions

- It is necessary to characterize the fluid under study in terms of the same components of the kinetic model, in order to achieve a better fit.
- Viscosity is important to match separately from the other properties, because this has numerical dependence of other parameters.
- The temperature distribution, the advancing front and flue gas composition are indicative in order to infer whether there is a good response to fluid and environment development process.
- Selection of pseudocomponents should be grouped according to tests distillation or by review of the behavior of the values of the equilibrium constants.
- A greater number of tests and reported properties allow bettering characterizing the fluid under study. It is at the discretion of the engineer develops establish in what order and what parameters setting used to adequately represent the behavior.

Selected References Cited

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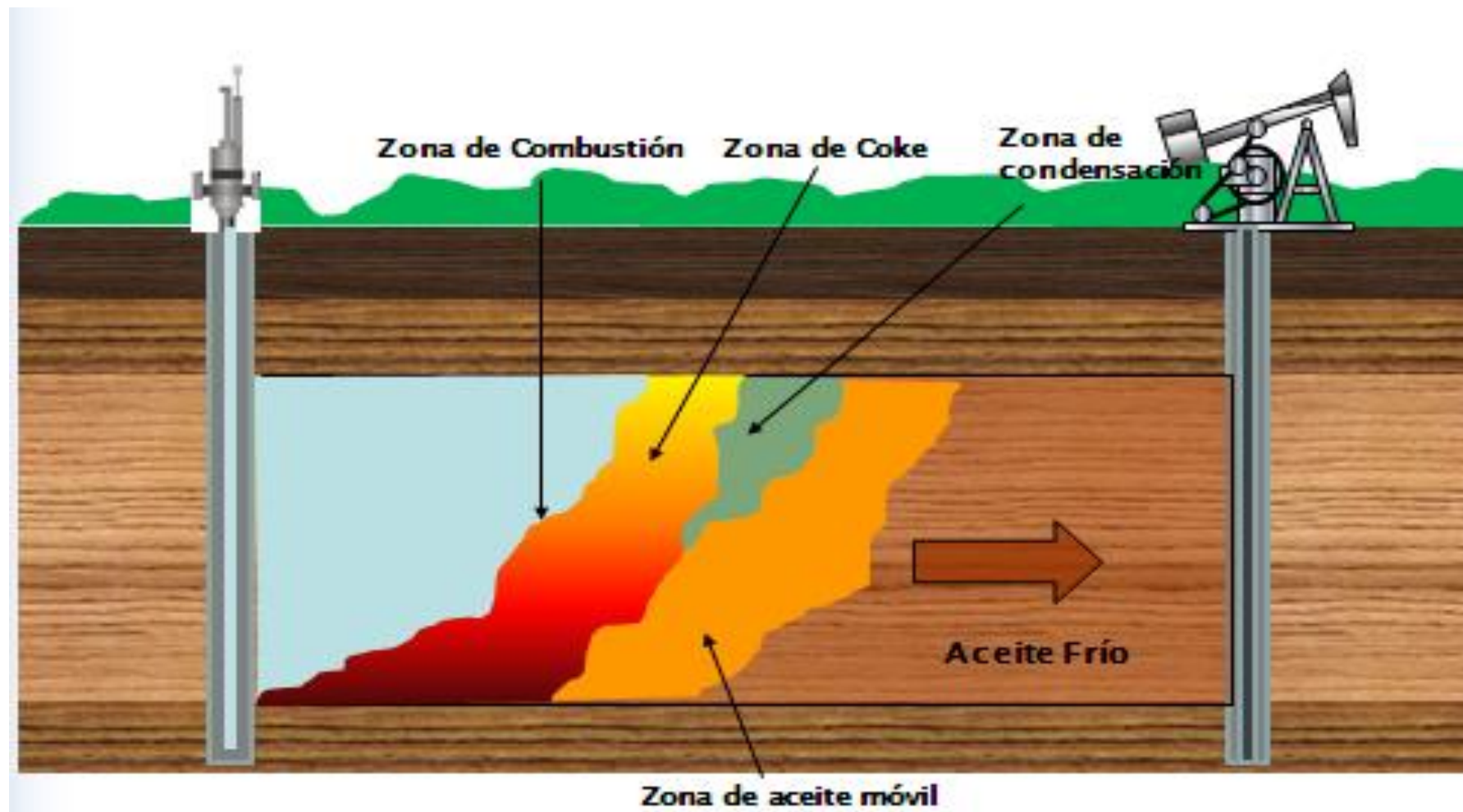


Figure 1. *In situ* combustion process scheme. Taken and edited from: Oliveros L, Informe de tubo de combustión, Grupo de Recobro mejorado, Universidad Industrial de Santander, 2009.

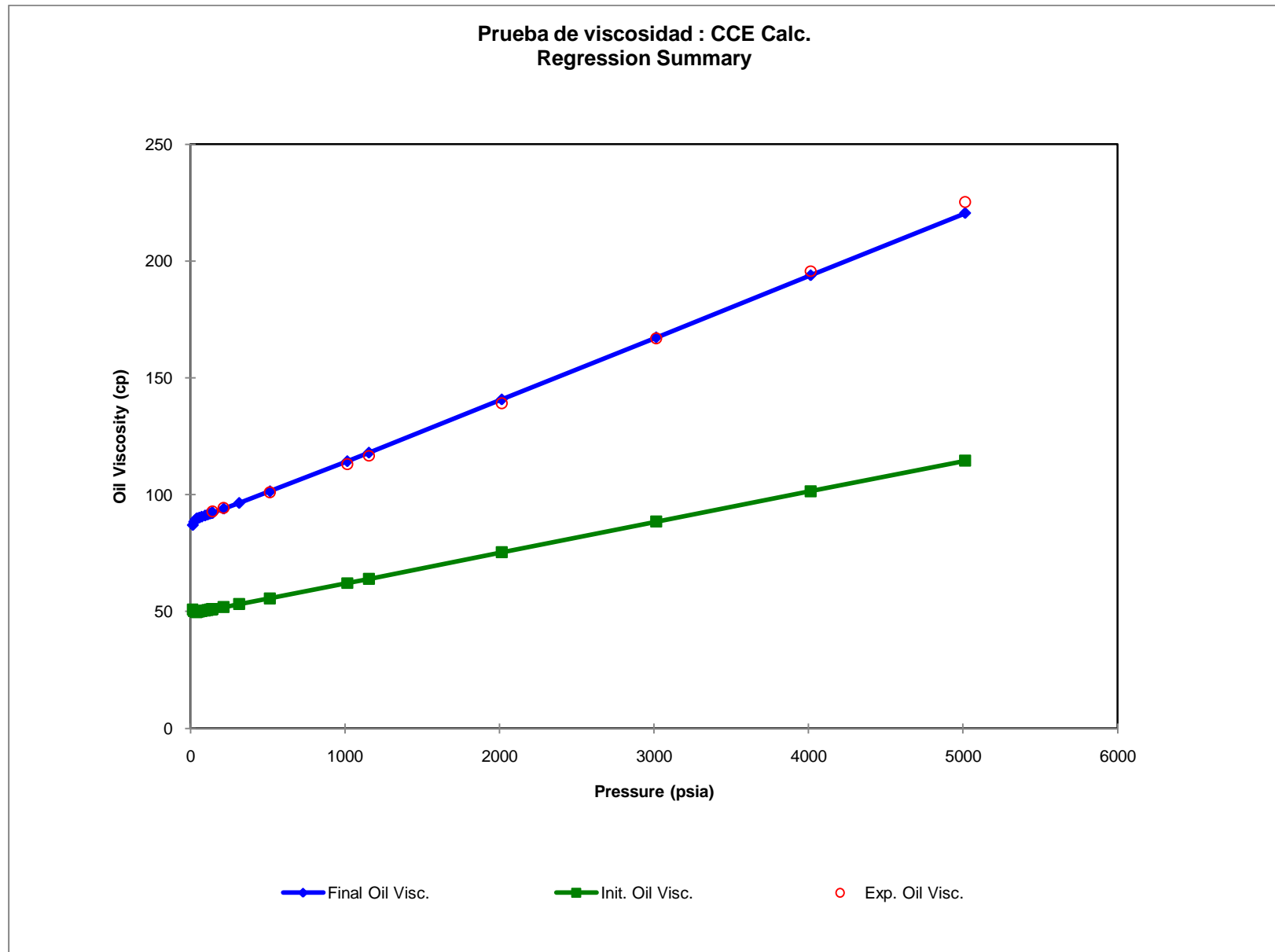


Figure 2. Matching for oil viscosity. Taken from: Builder, CMG.

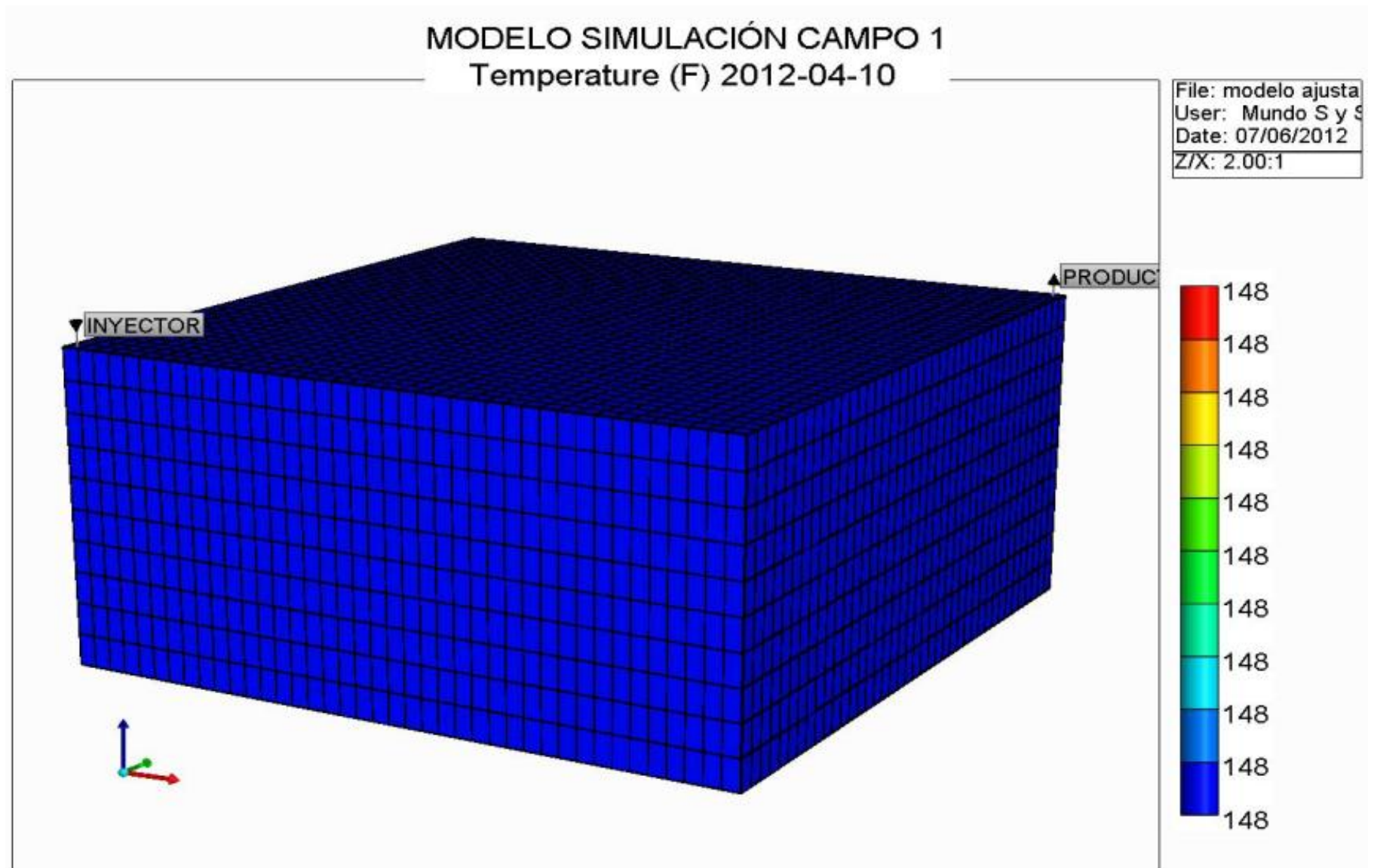


Figure 3. Simulation model. Taken from: Steam, Thermal and advanced recovery processes simulator (STARS), CMG.

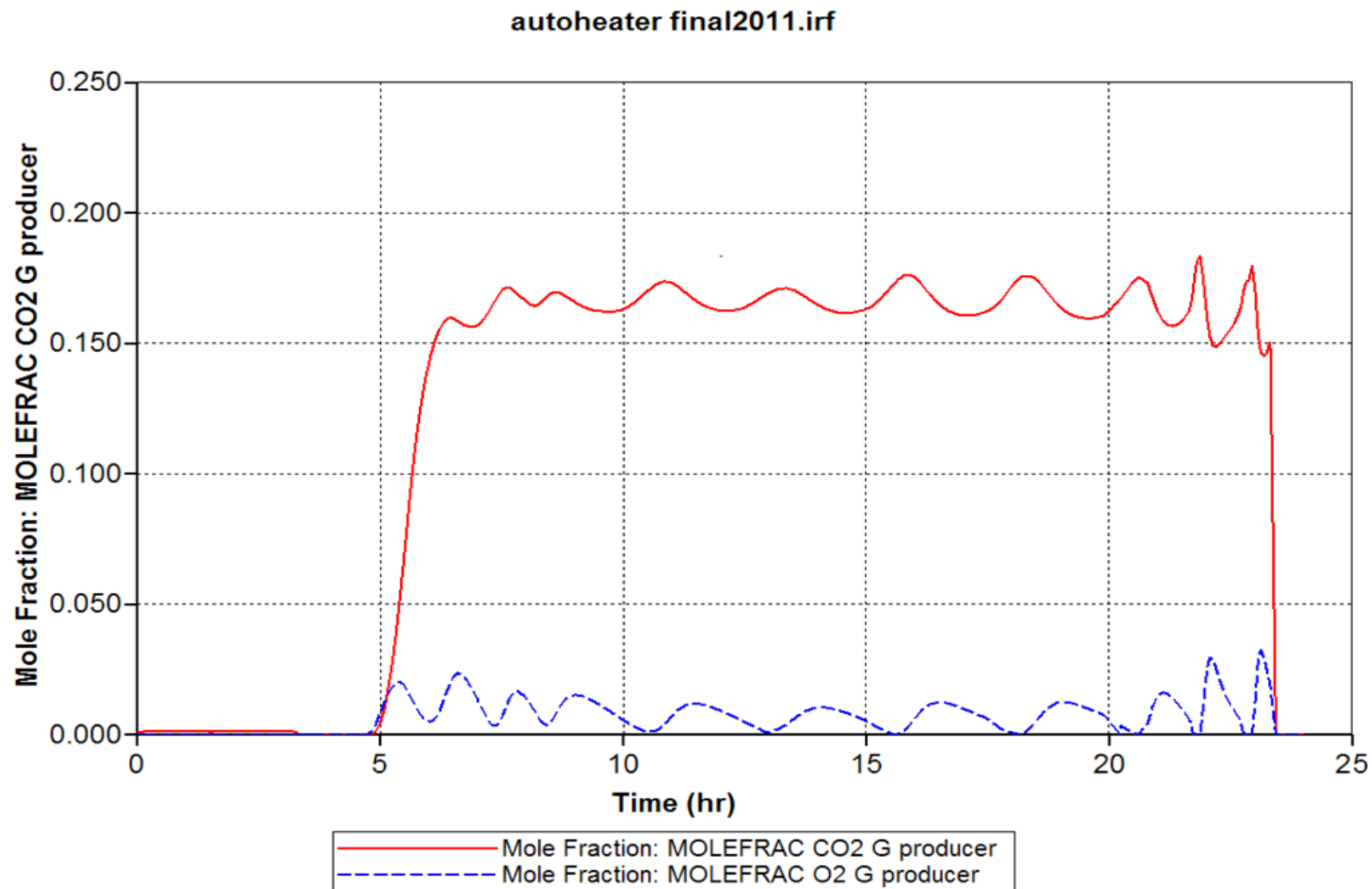


Figure 4. Gas composition. Taken from: CMG, Results graph.

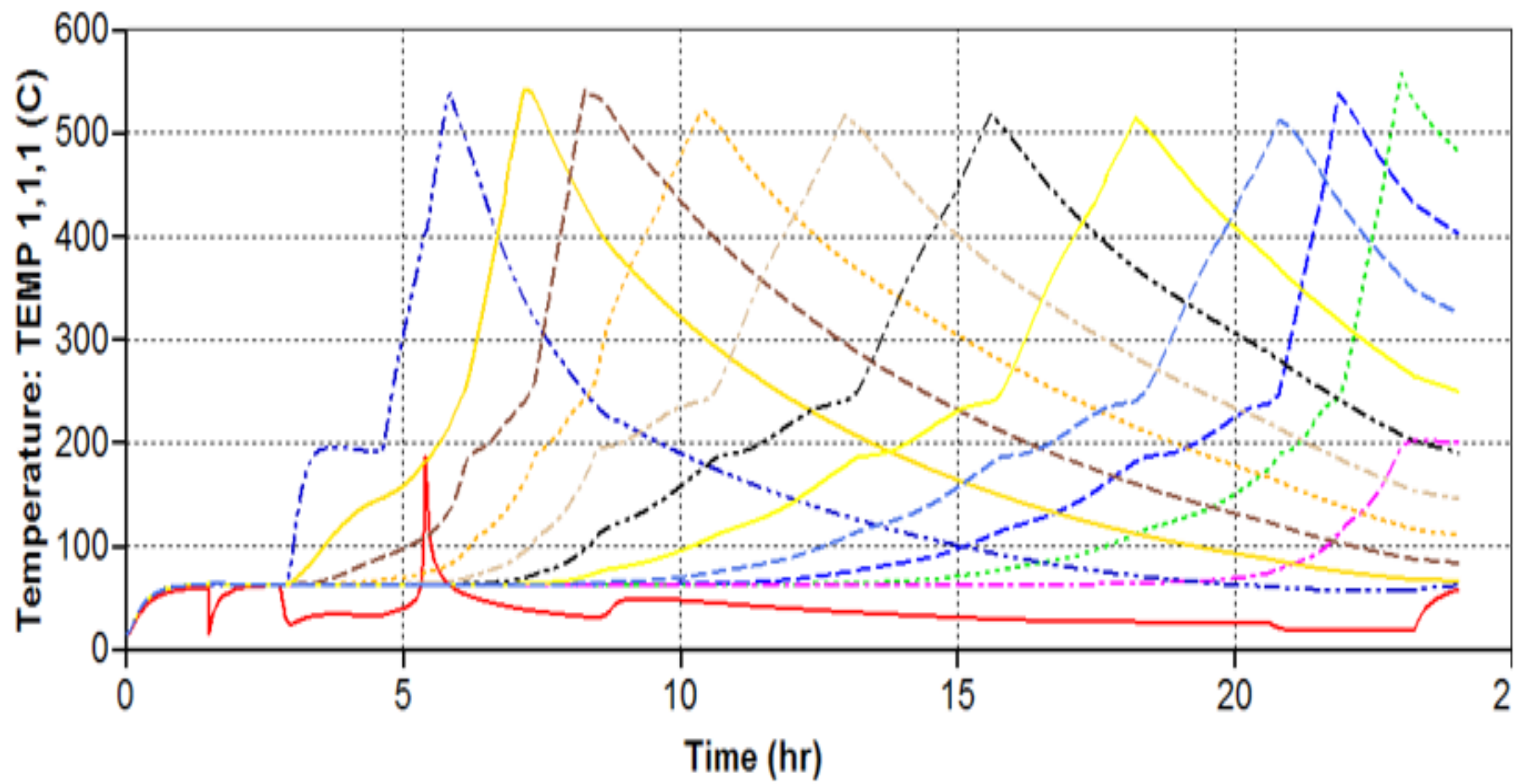


Figure 5. Temperature profiles. Taken from: CMG, Results graph.

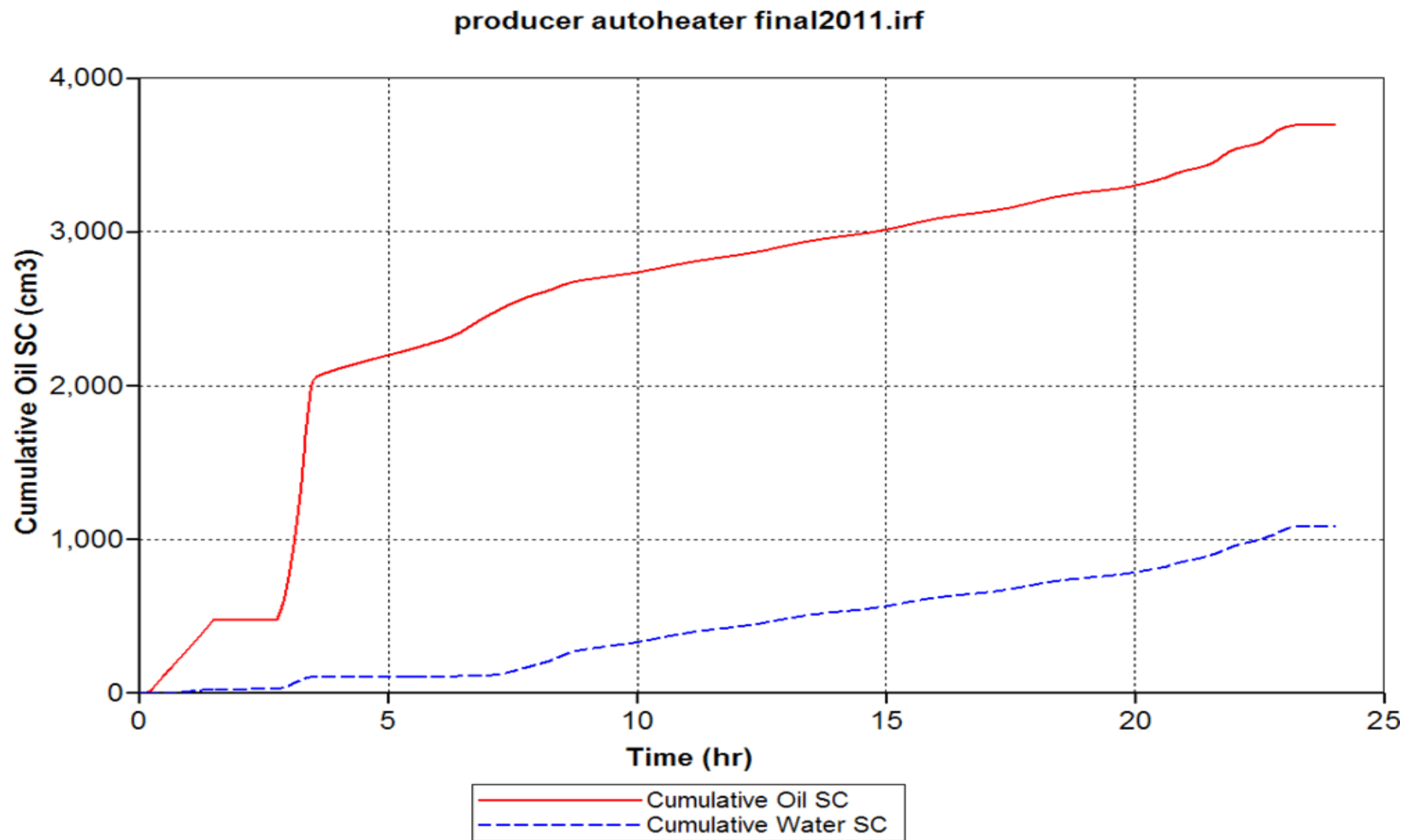


Figure 6. Cumulative fluid productions. Taken from: CMG, Results graph.