

Capacitance Resistive Models (CRMs)

Capacitance Resistive Model was presented by Yousef *et al* (2005), to quantify the communication between wells during secondary recovery operations based on injection and production flows. It takes into account capacitive (compressibility) and resistive (transmissibility) effects. For each producer-injector pair, two parameters are determined: one to quantify the connectivity and another that quantifies the degree of fluid storage between wells (time constants, *Taus*). The connectivity coefficients in CRMs represent the fraction of water injected in steady state that contributes to the production in each connected producer. There are different versions of CRM depending on the control volume. When studying the drainage volume around a producing well, the method is called CRMP. This is the version of the method implemented in Sahara.

The CRMP method is used in Sahara's pattern simulator as a method of assigning the distribution coefficients of the injection over time. The connectivity of the CRMs can be interpreted as the time distribution coefficients of the injection pattern simulator and only the injection and production data are required as input data. In addition, the time constants of the CRMs simulate the response delay in the producer due to the injection. In this way, we can simultaneously obtain the areal distribution coefficients of the injection (for each flow element) and an estimate of the time response (for each producing well), based on the production history.

The implementation of the CRMP model in the Sahara pattern simulator is multilayer and multistage. The model is adjusted using injections at the layer level and well-level productions as input data. The coefficients change in time according to the dynamics of the flow elements taking also into account the information of the injection - production data.

Terms of use of the methodology

The methodology proposed here for the initialization of the areal distribution coefficients of the injection depends only on injection and production data. To obtain good results from it, it is necessary to take into account the following points:

- *Injection data by layer*: the injection assigned in each layer for each injector well is considered as an individual injector well which we call "*Injector Layer*". Therefore, the measurement or estimation of injection allocation per layer must be taken into account when evaluating the quality of the adjustment.
- *Production data*: the production data used for the adjustment are the monthly productions of secondary liquid at producer well level. To calculate this secondary liquid, the input primary production of the total liquid is subtracted. Therefore, the quality of the primary production estimate may be important to evaluate the adjustment.
- *High frequency of changes in the injection patterns*: the continuous change of dynamics in the injection patterns can generate flow elements that last for very short time. These cases can generate anomalies when studying the temporal evolution of the coefficients over time.

- *Gaps in injection - production data*: the lack of data in the history of production produces the generation of a greater number of stages for a producer - injector layer pair increasing the periodicity of the changes of the patterns.

Workflow for liquid adjustment using CRMP

1. Flow elements are generated for each producer-injector pair in each layer throughout the life of a secondary recovery project. In CRM processing we start from the "drawn" patterns in the project.
2. The pore volume of the flow elements must be calculated first. The CRMP method will not take into account flow elements with pore volume equal to zero.
3. The CRMP option is chosen in the "Injection Distribution Coefficients" window

Areal Injection distribution coefficients	
Operation	Initialize Coefficients
Distribution Method	CRMP
CRMP - Advanced options	
Taus	Unknown
Tau Max	12
Iterate over base solution	<input type="checkbox"/>
Matrix stabilization mode	Automatic
MuF/MuID Value	1
Coefficients processing mode	Stop only when no Inj. data
Fill production gaps	<input type="checkbox"/>
Max Months with no activity	3

Coefficients initialization
This procedure calculates, according to the selected method, the areal injection distribution coefficients for each flow element for the selected dates and layers

Apply Cancel

CRMP Options

Taus

- *Unknown*: means that the *taus* are unknown and the algorithm will identify them together with the injection distribution coefficients.
- *Tau Max*: by default it is established in 12 months. This parameter was incorporated because instabilities were observed when the *Taus* are very large. $\text{Tau} = 12$ is within the expected values for the projects studied. The value is editable.
- *Input*: means that the *taus* are input data (the same value for all wells) and the algorithm will only identify the injection distribution coefficients.

Iterate over base solution

By default it is not selected. A solution is obtained that consumes short calculation time and is ideal to define the parameters for the identification. When this option is selected, the algorithm tries to improve the identification by optimizing the *taus*. The solution obtained is always better or the same as that obtained without iterating, but in some cases it may not produce any improvement.

Matrix Stabilization

When the inverse problem of the identification of coefficients in CRMP models is solved (minimization of the objective function), internally a matrix system is solved that must be well conditioned. When the developed algorithm is applied to real secondary recovery projects,

operational problems appear that generate bad conditioning of the matrix and the resulting system is unsolvable.

Many times the injection rates per layer are not available from independent measurements and they must be inferred from the wellhead rate, distributing this flow in the different layers in percentages according to some criteria. In these cases (in which the injection is layered by layer and the rates are proportional to each other for the layers of the same injector well) there is not enough information and the equations become linearly dependent, therefore, the system cannot be solved.

Another circumstance under which a bad conditioned problem is obtained is when the production data per stage is not enough for the reconstruction. These situations are common in projects with many changes in the dynamics of the patterns.

To solve these cases, two parameters were added to the algorithm: μ_F and μ_{ID} . They allow to correct bad conditions of the resulting matrix during the minimization of the objective function: μ_F adds restrictions to the problem to convert them into the missing equations of the system: μ_{ID} distorts the matrix system. This allows obtaining one of the possible solutions for the coefficients respecting the adjustment of the liquid flow rates at the producer well level. Under these circumstances, the methodology allows to accelerate the process of historical adjustment of liquid but requires analysis and validation in detail by the engineer.

The recommended strategy to run the identification algorithm is the following:

- a. The algorithm is run with $\mu_F = 0$, $\mu_{ID} = 0$. This gives us a first idea of the quality of the project data.
- b. If it does not run and a report of the presence of collinearities or bad conditioned matrices due to lack of information is generated, the run is repeated with $\mu_F > 0$, $\mu_{ID} = 0$. In this way we can see if the problem is solved with the incorporation of restrictions to the system.
- c. If that was not enough, the run is repeated with $\mu_F > 0$, $\mu_{ID} > 0$.

During the validation stage of the algorithm, different tests were carried out to determine the range of μ_f / μ_{ID} values that allow solving the resulting matrix system without significantly altering it. Values between (0.0001 - 10) can be tested without problems. The default value is 1 for the two parameters. This ensures the resolution of the system in reasonable times.

The *Matrix Stabilization* option in *Automatic* mode generates this process automatically with the entered μ_F / μ_{ID} values. The two parameters take the same value in the automatic process. The *Manual* option allows running with specific values of the stabilization parameters.