

# Determination of contribution proportion of injection wells in oil production by interwell tracer method using partitioning organic compounds from crude oil

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## Summary

Waterflooding is one of the most common secondary oil recovery methods because of its economic efficiency. In case where many injection wells contribute to the oil recovery process of a production well, contribution proportion will be an important parameter for management of water injection. Besides the well-known Interwell Tracer Tests using artificial tracers injected into the reservoir, the method of using partitioning organic compounds in crude oil as Natural Partitioning Interwell Tracers (NPITs) shows a great potential for evaluating the contribution proportion of injection wells in oil extraction process. The paper presents the research results to illustrate an idea of using NPITs for calculation of the contribution of injection wells to a production well in homogeneous single-layered reservoir on UTCHEM simulation data with Five-spot model and Direct-line model. The results showed that the calculated values of contribution proportion are different from modelling values between 1 - 2%.

**Key words:** NPITs, numerical model, contribution proportion, water injection.

## 1. Introduction

The interwell tracer method is well-known as an effective tool for studying flow dynamics in porous or fractured media of reservoirs. Besides the method using artificial tracers injected into the reservoir, organic compounds such as alkylphenols (APs) and aliphatic acids (AAs) are naturally existing in crude oil and able to dissolve into water phase depending on oil/water partition coefficient  $K_d$  used as natural partitioning interwell tracers (NPITs) for oil saturation and swept pore volume calculation [1, 2]. During oil displacement process by waterflooding, the concentration of NPITs decreases over time when diffusing from oil phase into water phase [3, 4]. In case the oil recovery process of a production well is contributed by many injection wells, the concentration of NPITs in water phase at the production well is the total concentration of NPITs contributed by component swept areas. The NPITs concentration curve of each swept area can be determined by deconvolution of the differential total concentration curve. Based on calculation of the mean residence time of NPITs in each swept area, it is

possible to determine the contribution proportion of component swept areas.

The proposed method has been tried on the data simulated by UTCHEM in Five-spot model and Direct-line model of homogeneous single-layered reservoir.

## 2. Theory

Suppose that the reservoir consists of two phases of oil and water. The advection - dispersion - exchange transport of NPITs compound  $k$  between phases is given by the equation [2]:

$$\varphi \frac{\partial}{\partial t} (\sum_{p=1}^{n_p} S_p C_{kp}) + \nabla \cdot (\sum_{p=1}^{n_p} (C_{kp} \vec{u}_p - \varphi S_p \vec{K}_{kp} \times \nabla C_{kp})) = 0 \quad (1)$$

In which,  $\varphi$  is porosity of media,  $n_p = 2$  is number of phases ( $p = w$ : water phase,  $p = o$ : oil phase);  $S_p$  is saturation of phase  $p$ ;  $C_{kp}$  is concentration of compound  $k$  in phase  $p$  [M/L<sup>3</sup>];  $\vec{K}_{kp}$  is dispersion tensor of compound  $k$  in phase  $p$  [L<sup>2</sup>/T];  $\vec{u}_p$  is velocity of phase  $p$  [L/T];  $t$  is time [T].

Equation (1) can be solved with the following assumptions: the concentration of compound  $k$  between phases instantaneously reaches equilibrium while oil/water in contact, the partition coefficient  $K_d$  of compound  $k$  is constant, no mass transfer of compounds on the

boundaries of studied zone except the boundaries of injection well and production well, the diffusion effect is ignored due to the high velocity of water, the degradation, absorption and interaction of compounds are not considered.

From Equation (1) Akasawa showed the expression of mean residence time of NPITs compound  $k$  [2]:

$$\bar{t}_k = \int_0^\infty [1 + (f_w + K_{dk}f_o) \left( \frac{C_{kw} - C_{kwl}}{C_{kwl}} \right)] d\tau \quad (2)$$

In which,  $K_{dk}$  is the partition coefficient of compound  $k$ ;  $f_w, f_o$  are fraction of water phase and oil phase in fluids at production well, respectively.

Let  $C_{kA} = C_{kwl} + (f_w + K_{dko} \times f_o) \times (C_{kw} - C_{kwl})$  be the apparent concentration of compound  $k$ , mean residence time is given in equivalent form:

$$\bar{t}_k = \frac{1}{C_{kwl}} \times \int_0^\infty C_{kA} d\tau \quad (3)$$

The differential distribution of apparent concentration  $C'_{kA} = \partial C_{kA} / \partial t$  has the form of chromatographic peak as illustrated in Figure 1, in which its mean residence time (4) is proven to be equal to the mean residence time of apparent distribution in Equation (3):

$$\bar{t}'_k = \frac{\int_0^\infty \frac{\partial C_{kA}}{\partial t} \times t dt}{\int_0^\infty \frac{\partial C_{kA}}{\partial t} dt} = \frac{1}{C_{kwl}} \times \int_0^\infty C_{kA} dt = \bar{t}_k \quad \begin{cases} C_{kA} = C_{kwl} & t = 0 \\ C_{kA} = 0 & t \rightarrow \infty \end{cases} \quad (4)$$

In case the oil recovery process of a production well is contributed by many injection wells, the concentration of NPITs in water phase at the production well is the total concentration of NPITs contributed by component swept areas. The differential distribution of apparent concentration of each swept area can be determined to calculate the mean residence time of NPITs in each swept area, therefore the contribution proportion of respective injection wells  $F_i$  is determined.

$$F_i = \frac{1}{1 + \bar{t}_{ki} \sum_{j \neq i} \frac{1}{\bar{t}_{kj}}} \quad (5)$$

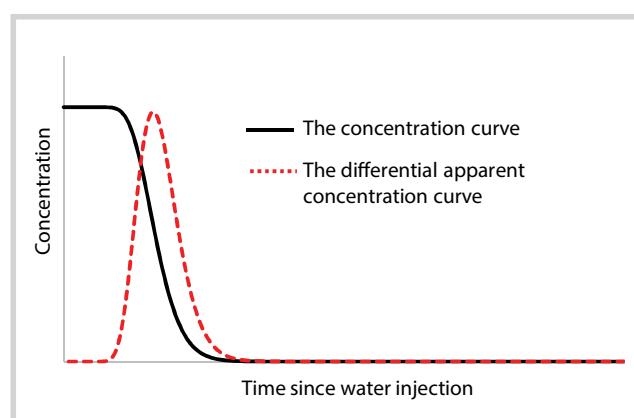
Equation (5) is based on assumptions such as reservoir is homogeneous single-layered and the distances between the injection wells and the production well are the same.

### 3. Simulation results

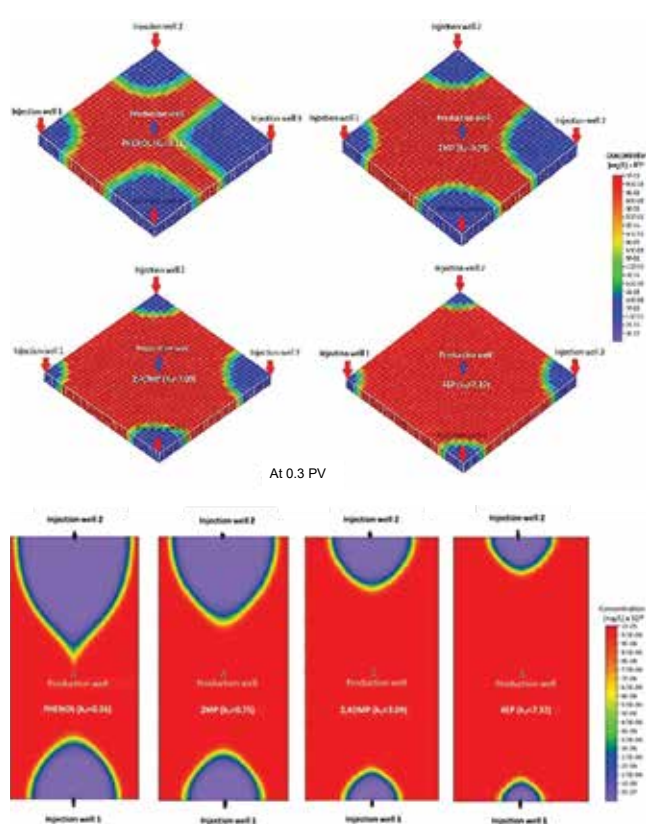
UTCHEM (The University of Texas's Chemical Simulator) is a software for simulating multiphase and

multicomponent reservoir model developed by Texas University. UTCHEM allows simulation of advection - dispersion and exchange of solutes between phases in reservoir media, including the leaching process of organic compound from oil phase to water phase during oil production [5].

UTCHEM was used to run 3D reservoir model with two water injection patterns: Five-spot pattern - common pattern in stratified sediment reservoir and Direct-line



**Figure 1.** Illustrating the apparent concentration curve of NPITs compound and its differential curve. The differential distribution of apparent concentration is in the form of a chromatogram.



**Figure 2.** Concentration distribution in space of phenol, 2-methylphenol, 2,4-dimethylphenol, 4-ethylphenol at 0.3 PV in Five-spot model and Direct-line model.

pattern - typical pattern in edge water injection or gravity injection.

The models have initial oil saturation of 0.65 and initial water saturation of 0.35.

The Five-spot model includes 4 injection wells and a production well having the size of 132m x 132m x 15m

divided into 33 x 33 x 4 grid cells. The total flow rate is 261.36m<sup>3</sup>/day with contribution proportion of injection wells equal to 10:20:30:40 (%).

The Direct-line model includes 2 injection wells and a production well having the size of 102m x 204m x 8m divided into 25 x 51 x 4 grid cells in corresponding ratio

Table 1. The partition coefficient  $K_d$  of NPITs used in the models

NPITs	Partition coefficient $K_d = C_o/C_w$	Initial concentration in oil (mg/L)	Initial concentration in water (mg/L)
Phenol	0.16	1.6	10
4-Methylphenol	0.58	5.8	10
2-Methylphenol	0.75	7.5	10
4-Propylphenol	1.34	13.4	10
3,4-Dimethylphenol	1.61	16.1	10
2,4-Dimethylphenol	3.09	30.9	10
4-Ethylphenol	7.37	73.7	10

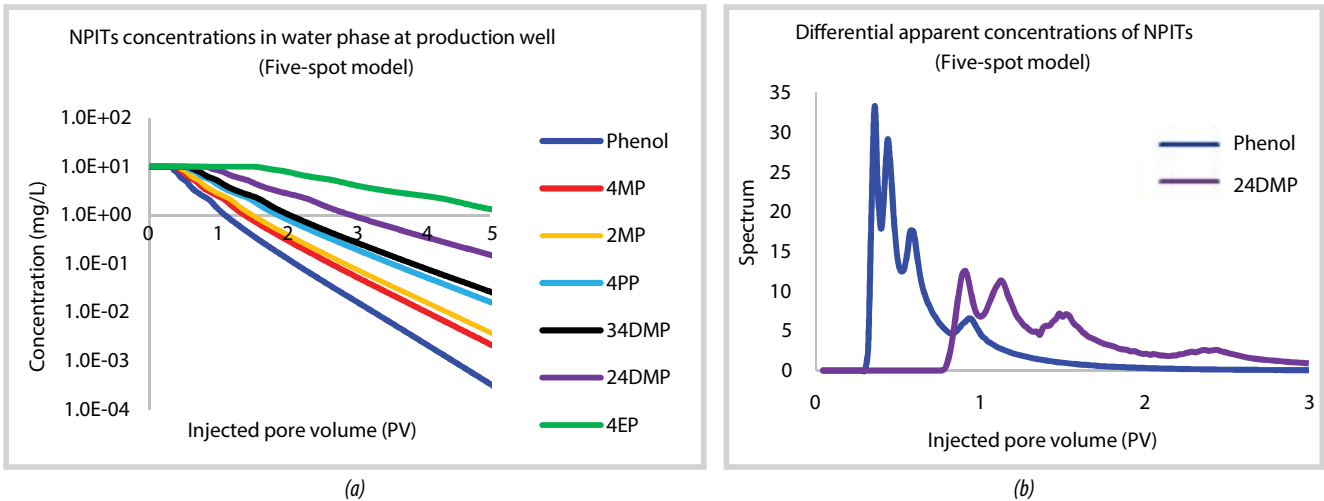


Figure 3. NPITs concentration curves in water phase at production well of Five-spot model (a) and its differential apparent concentration (b) of phenol ( $K_d = 0.16$ ) and 2,4-dimethylphenol ( $K_d = 3.09$ ). The chromatogram shows the effect of four swept areas on NPITs concentration at production well.

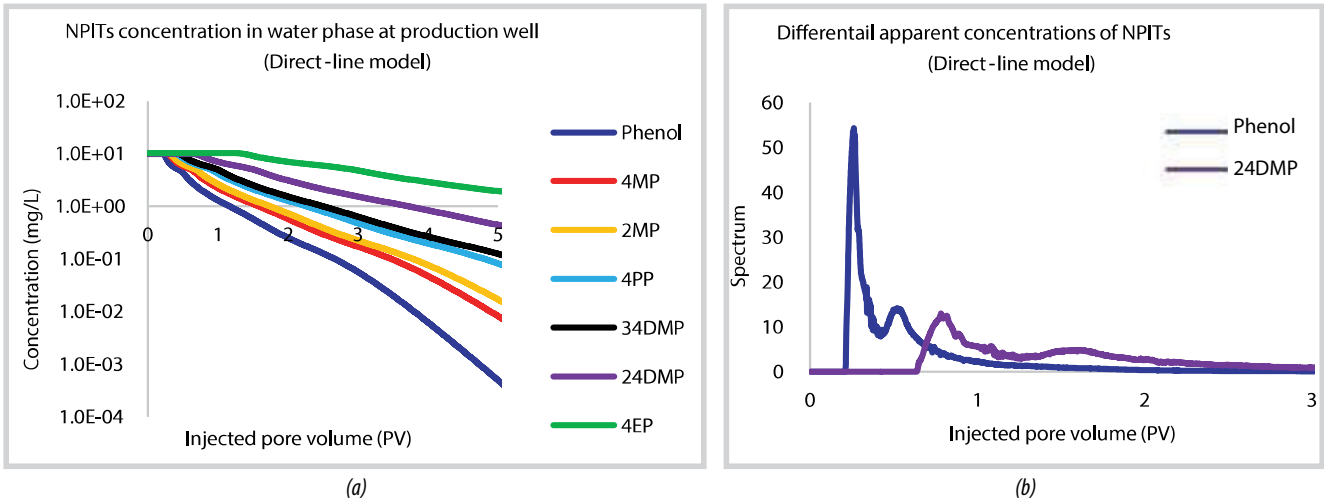


Figure 4. NPITs concentration curves in water phase at production well of Direct-line model (a) and its differential apparent concentration (b) of phenol ( $K_d = 0.16$ ) and 2,4-dimethylphenol ( $K_d = 3.09$ ). The chromatogram shows the effect of two swept areas on NPITs concentration at production well.

of length to width  $d/a = 2$ . The total flow rate is  $200\text{m}^3/\text{day}$  with contribution proportion of injection wells equal to 30:70 (%).

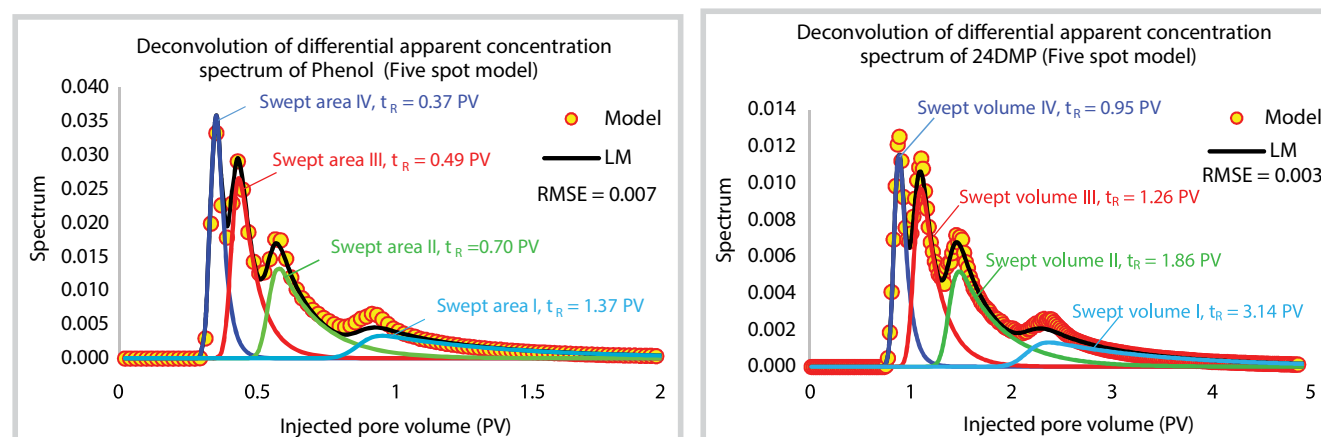
The general parameters of the models are:

- Porosity  $\phi = 0.2$ , water viscosity  $\mu_w = 0.7\text{cp}$ , oil viscosity  $\mu_o = 4\text{cp}$ ;
- Longitudinal and transverse dispersivity are  $\alpha_{DL} = 0.03\text{m}$ ,  $\alpha_{DT} = 0.003\text{m}$ ;
- Relative permeability curve is described by Corey model with critical water saturation  $S_{cwr} = 0.3$ , residual oil saturation  $S_{or} = 0.35$ , water endpoint: 0.15, oil endpoint 0.85, water exponent: 1.5, oil exponent: 2, endpoint mobility ratio: 1.

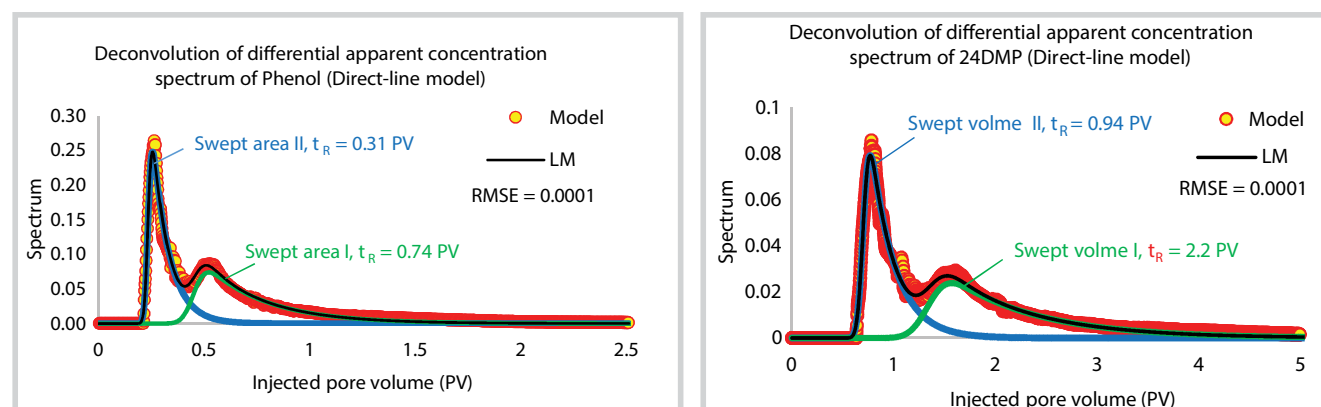
The NPITs initial concentration in oil phase and water phase and its partition coefficient between phases determined in the experimental data of Tracer Lab of CANTI are listed in Table 1. All compounds are supposed to have the same density, alkane number and chemical properties but different partition coefficient.

The waterflooding lasts 10 PV of the model to obtain the whole concentration curves of the NPITs at the production well. The concentration of NPITs between phases instantaneously achieves equilibrium while oil/water are in contact. Figure 2 illustrates NPITs concentration distribution of the models at 0.3 PV. Figures 3a and 4a show NPITs concentration curves at the production well decreased over time, in which the greater  $K_d$  the slower reduction of concentration. The Levenberg-Marquart (LM) algorithm and Exponential Modified Gauss (EMG) function were applied to determine the differential apparent concentration curve of each swept area. The corresponding differential apparent concentrations illustrated in Figures 3b and 4b have the form of overlapping chromatographic peaks, in which the mean residence time of each peak equal to the mean residence time of NPITs representing the injection mode of the respective swept area.

Figures 5 and 6 show the results of applying LM algorithm to separate the overlapping chromatographic



**Figure 5.** Differential apparent concentration of phenol ( $K_d = 0.16$ ) and 2,4-dimethylphenol ( $K_d = 3.09$ ) of Five-spot model is obtained after using LM algorithm. The mean residence time  $t_R$  of NPITs in each swept area is determined by using corresponding chromatographic peak.



**Figure 6.** Differential apparent concentration of phenol ( $K_d = 0.16$ ) and 2,4-dimethylphenol ( $K_d = 3.09$ ) of the Direct-line model is obtained after using LM algorithm. The mean residence time  $t_R$  of NPITs in each swept area is determined by using corresponding chromatographic peak.

Table 2. The results of calculating the contribution proportion of injection wells of Five-spot model and Direct-line model

Model	Five spot model				Direct-line model	
Swept area	I	II	III	IV	I	II
Contribution ratio of swept areas of models (%)	10	20	30	40	30	70
The mean residence time of NPITs in swept areas $\bar{t}$ (PV) calculated from Equation (4). The contribution proportion of injection wells $F$ (%) calculated from Equation (5) and the difference from model value $d$ (%) are given below.						
<b>Phenol (<math>K_d = 0.16</math>)</b>						
$\bar{t}$ (PV)	1.37	0.70	0.49	0.37	0.74	0.31
$F$ (%)	10.6	20.6	29.8	39.0	29.7	70.3
$d$ (%)	0.6	0.4	0.2	1.0	0.3	0.3
<b>4MP (<math>K_d = 0.58</math>)</b>						
$\bar{t}$ (PV)	1.65	0.88	0.60	0.46	0.92	0.40
$F$ (%)	10.9	20.4	29.7	39.0	30.2	69.8
$d$ (%)	0.9	0.0	0.3	1.0	0.2	0.2
<b>2MP (<math>K_d = 0.75</math>)</b>						
$\bar{t}$ (PV)	1.77	0.95	0.65	0.49	1.06	0.45
$F$ (%)	10.9	20.3	29.7	39.0	29.7	70.2
$d$ (%)	0.9	0.3	0.3	1.0	0.3	0.2
<b>4PP (<math>K_d = 1.34</math>)</b>						
$\bar{t}$ (PV)	2.18	1.18	0.81	0.61	1.37	0.59
$F$ (%)	11.0	20.3	29.6	39.1	30.3	69.7
$d$ (%)	1	0.3	0.4	0.9	0.3	0.3
<b>34DMP (<math>K_d = 1.61</math>)</b>						
$\bar{t}$ (PV)	2.37	1.29	0.88	0.66	1.50	0.63
$F$ (%)	11	20.2	29.6	39.2	29.6	70.4
$d$ (%)	1	0.2	0.4	0.8	0.4	0.4
<b>24DMP (<math>K_d = 3.09</math>)</b>						
$\bar{t}$ (PV)	3.14	1.86	1.26	0.95	2.20	0.94
$F$ (%)	11	20.1	29.6	39.3	29.9	70.1
$d$ (%)	1	0.1	0.4	0.7	0.1	0.1
<b>4EP (<math>K_d = 7.37</math>)</b>						
$\bar{t}$ (PV)	5.72	3.49	2.37	1.78	4.16	1.86
$F$ (%)	12.1	19.8	29.2	38.9	30.9	69.1
$d$ (%)	2.1	0.2	0.8	1.1	0.9	0.9

peaks of phenol ( $K_d = 0.16$ ) and 2,4-dimethylphenol ( $K_d = 3.09$ ). The mean residence time of NPITs in each swept area can be determined by using corresponding chromatographic peak. The greater  $K_d$  the greater mean residence time of NPITs in each swept area and vice versa. The results of calculating the contribution proportion of injection wells of the Five-spot model and the Direct-line model are presented in Table 2.

The calculated contribution proportion values are different from the model values in range of 1 to 2% for all NPITs in both models. The compounds having  $K_d$  smaller

than 3 allow for the calculation from 0 to 3 PV whereas those having  $K_d$  more than 3 need greater observation time period. The results show the applicability of the interwell tracer method using NPITs for evaluating the contribution proportion of injection wells in oil extraction process on both the Five-Spot and Direct-line models.

#### 4. Conclusions

The movement of partitioning organic compounds (NPITs) in the case of many injection wells contributing to the oil recovery process of a production well is simulated

on the UTCHEM software with the Five-spot model and the Direct-line model. The contribution proportion of swept areas can be determined by using mean residence time of NPITs in corresponding swept area. The calculated values are then compared with the model to assess the feasibility of the method.

The NPITs having  $K_d$  smaller than 3 are more suitable to calculate contribution proportion values at the stage of up to 3 PV of injection volume, while other NPITs having  $K_d$  greater than 3 are more suitable to longer injection period.

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