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Research Article

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Modeling of Chemical Water Shut off Treatments

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Abstract

Water production is one of the major problems that been encountered in the oil industry, which may cause corrosion of tubular, fine migration and acceleration of well abandonment. More than $40 billion is spent yearly dealing with unwanted water, so a treatment should be implemented to reduce high water production.

Many papers investigated and focused their researches on how to reduce water cut percentage. Mechanical and chemical treatments are suggested, chemical treatment represented in polymer-gel with cross linker solution proved optimistic results.

Gel can solve many types of water production problems rather than other chemical or other mechanical treatments. In this paper a model was constructed to determine the applicability of gels in reducing water permeability. The model included equations predicted using statistical software (SPSS) that determines the water residual resistance factor (F_{rrw}) and the oil residual resistance factor (F_{rro}) by inserting polymer concentration then determine the optimum concentration which gives the most desired results.

A real field data was obtained from Z field (well X, well Y, and Well Z) and gel applicability in permeability reduction had been tested, then an optimistic result obtained.

The outcomes of this study investigate that there is a great chance to apply polymer-gel as water shut-off technique. For future work a full core-flooding study must be constructed to obtain more set of data and improvement of the equations accuracy.

Keywords: Cross Linkers, Permeability, Polymer Gel, Residual Resistance Factor, Salinity

Introduction
Background
Water production is a serious technical, environmental and economic problems associated with produced oil and gas. It can accelerate the abandonment of oil and gas wells and can cause many problems such as: corrosion of tubular, fine migration and hydrostattic loading. Excessive water production can be treated with several chemical and mechanical solutions. Chemical systems play a crucial role in field process for improving oil recovery and water shut-off treatments. Chemical treatments are not suitable for all types of excessive water production but in the right circumstances major economic benefits can be realized. Chemical treatments require accurate fluid displacement to successfully enter the formation and thus shutting–off the water, different types of gel systems, organic cross linkers, metallic cross linkers for improving flooding efficiency to reduce water production and improve oil recovery.

Liao et al. (2014) demonstrates that gel treatment has been wildly used in more than 20 counties around the word including: China, United States, Canada, Mexico, France, Brazil, Indonesia, Venezuela, and Turkey. After a short time, high successful rate and low cost are the main advantages for this method. However, gel treatment as a chemical treatment has its own limitations. By selecting a proper candidate, the success rate can be measured. Injection volume, fluid pH, temperature and concentration should be carefully considered when using gel treatments.

Problem Statement
The worldwide daily water production is about 210 million barrels [33.4 million m3] of water produced every 75 million barrels [11.9 million m3] of oil.

Water handling costs are high estimate arrange from 10 to more than 50 cents per barrel for water. In a well producing oil with 80% water cut , the cost of handling water can be as high as 4$ per barrel of oil produced. Water affects every stage of oilfield life starting from exploration (the oil water contact is an essential factor for determining oil in place) through development, production and finally abandonment.

Some oil fields produce more than eight barrels of water associated each barrel of oil. This production of water results in uncounted environmental damage cost, the production and disposal of this produced water cost more than (1.0 - 2.0) US$/bbl and this cost is increasing day after day.

Objectives

The main objective of this study is tounderstand the different mechanisms that contribute to excessive water production and treatments, as well as to evaluate applicability of chemical treatments in Sudanese oil field, In addition to design an optimum treatment for the wells that suffering from excessive water production that aims to design an economical model compares the cost of handling produced water before and after treatment.

Material and Methods

A set of data collected, this type of data is relating between the residual resistance factor for both oil and water (the ratio between phase mobility before to after treatment F_{rrw},F_{rro}) , the polymer concentration (C) , effective permeability of oil and water before treatment (K_{wb}, K_{ob}) , salinity(S) and reservoir temperature (T).

Equations were predicted using a statistical software (SPSS) to determine the residual resistance factor for both oil and water after applying polymer-gel treatment, then a model had been constructed using an Excel sheet and the equations was inserted in.

The most important parameters the model determines is the water cut and the incremental in oil recovery after treatment. To test the model validation previous case studies data were applied and the results were matched.

Data collecting

This study starts from collecting gel treatment data (Data related between residual resistant factor F_{rr}, polymer Concentration and permeability before treatment).
By using SPSS, F_{rr} equations predicted for both oil and water.

Water residual resistant factor (F_{rrw}) Equation:

Table1: illustrate literature data relating F_{rrw} with polymer concentration

K_{wb}before, md	C%	F_{rrw}
600	0.3	13.7
800	0.3	18.27
1000	0.3	22.84
1200	0.4	84.16
1100	0.4	77.15
700	0.4	49
900	0.4	63.13
1200	0.5	200.9
950	0.5	159.09
1050	0.5	175.83

These above data been inserted to the SPSS, then this software analyze and relate F_{rrw} as a function of C and K_{wb} in an equation with a high (R^2=0.96) value.
Result obtained after input this data in SPSS:

$$Frrw = \frac{K_{wb}C^{3.97}}{0.43}$$

F_{rrw}: Water residual resistant factor.
K_{wb}: Water effective permeability before treatment, md.
C: Gel concentration (ppm)

Oil residual resistant factor (Frro) Equation:

Table2: illustrate literature data relating F_{rro} with polymer concentration

K_{ob}before, md	C%	F_{rro}
508	0.5	4.8
242	0.5	1.2
389	0.5	22.84
68	0.5	84.16
27.2	0.4	77.15
186	0.3	49
132	0.5	63.13

These above data been inserted to the SPSS, then this software analyze and relate F_{rr} was a function of C and K_{wb} in an equation with a high (R^2=0.9) value.
Result obtained after input this data in SPSS:

$$F_{rro} = 1.348\left[K_{ob}{}^{0.353} * C\right] - 0.804$$

F_{rro}: oil residual resistant factor.
K_{ob}: oil relative permeability before treatment (md).
C: Gel concentration (ppm).
Effect of Formation water salinity and reservoir temperature on F_{rr} :

$$F_{rrw} = \left[\frac{S}{T}\right]^{0.04}$$

$$F_{rro} = \frac{\ln(S)}{T^{0.45}}$$

S: Formation water salinity (mg/l) .
T: Reservoir temperature (C°).

Hint: F_{rrw}(s,t) equation is valid for salinity values ranged from (7000-12000)mg/l and initial water permeability ranged from (85-105) md.

F_{rro}(s,t) equation is valid for salinity values ranged from(0-50000) mg/l and initial water permeability ranged from (75-80) md.

The results obtained from these equations show that there is a little effect on the values of F_{rrw} and F_{rro} caused by salinity and reservoir temperature. So we neglect the effect of these two factors in the model calculation.

Model Construction

For the model construction, the reservoir characteristics, fluids properties and polymer concentration was inserted as an input data to calculate in the other side the residual resistance factor (Frr_w ,Frr_o), Water cut after treatment and the incremental in oil production.

Input data (fluid properties):

i Gel injection rate (ft3/hr).

ii Water salinity (mg/l).
iii Water viscosity (cp).
iv Oil viscosity (cp).
v Gel viscosity (cp).
vi Gel permeability in both oil and water layers (md).
vii Gel density (Ib/ft3)
viii Oil formation volume factor.
ix Polymer concentration

Input data (formation properties):

i Formation porosity.
ii Absolute permeability for both oil and water layer (md).
iii Thickness (ft).
iv Connate water.
v Residual oil.
vi Well bore radius (ft).
vii Reservoir radius (ft).
viii Reservoir pressure (psi).
ix Reservoir temperature (c).
x True vertical depth (ft).
xi Pore size distribution index.

Output data

Water residual resistance factor (frr_w)

$$Frr_w = \frac{K_{wb}}{0.4xC^{-3.9}}$$

Oil residual resistance factor (frr_o)

$$Frr_o = 1.348xK_{ob}^{0.353}xC - 1.04$$

Volume of gel

$$V = 0.56[H_1 x Ø_1 x(rp_1^2 - r_w^2) + H_2 \, x \, Ø_2 x(rp_2^2 - r_w^2)]$$

Gel radius of penetration

$$R = \{\frac{\left(\frac{qt}{\pi h - r_w^2}\right)}{[Ø(1 - S_{or})]}\}^{0.5}$$

Gelation time (hr)

$$T = 10^{-7} x \, EXP^{\frac{11000}{Rt}}$$

Water flow rate after treatment

$$Q_w = \frac{k \, k_{rwaff} \, h \, \Delta p}{141.2 \ln(r_e / r_w)}$$

Oil flow rate after treatment

$$Q_o = \frac{k \, k_{roaff} \, h \, \Delta p}{141.2 \, ln(r_e / r_w)}$$

Water cut after treatment

$$Wc = \frac{Q_w}{Q_w + Q_o}$$

Dilution effect

Polymer concentration mentioned in the equations above inserted without considering the dilution effect. The amount of water exists in the formation which the gel will reach must be determined to know the exact concentration should be added at surface before injecting the gel.

Economic evaluation

One of the most important questions that determine the success of any project is (Is this project economically feasible?) .So an economic evaluation is considered in the model by calculating the incremental in oil production revenue and money saved due to water cut reduction.

Results and Discussion

In this section a real field will be applied then the reduction in water cut increase in oil recovery and the total money saved after placement process will be measured.

Well X

Diagnose: water conning problem.
Treatment: Water coning is one of the problem that polymer – gel injection can solve, so the well data is applied to the model and thus the results obtained using different concentrations.

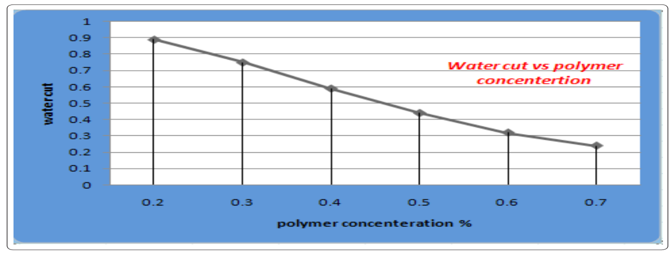

Figure 1: Water cut vs. polymer concentration

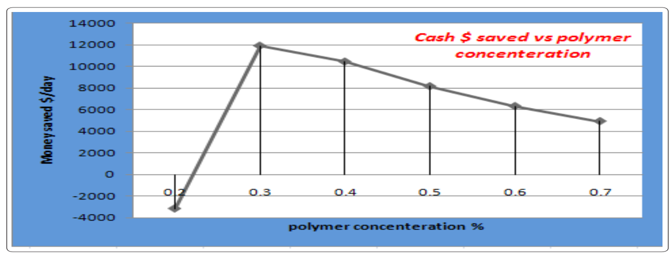

Figure 2: Total money saved vs. concentration

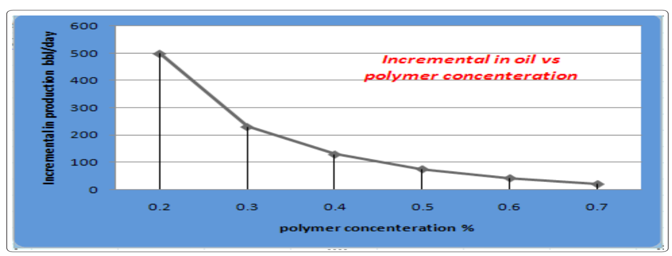

Figure 3: Incremental in oil vs. concentration

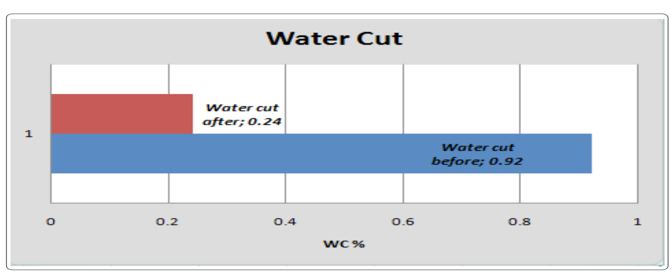

Figure 4: Water cut at optimum concentration

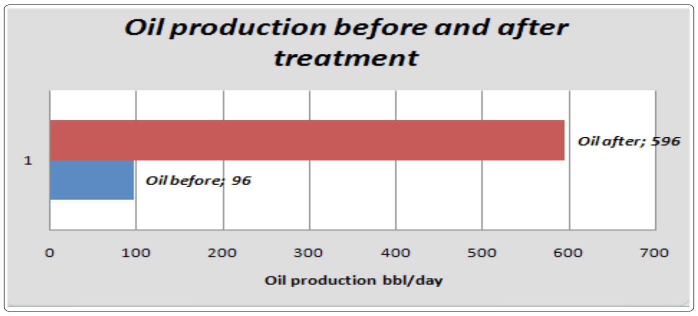

Figure 5: Oil productions at optimum concentration

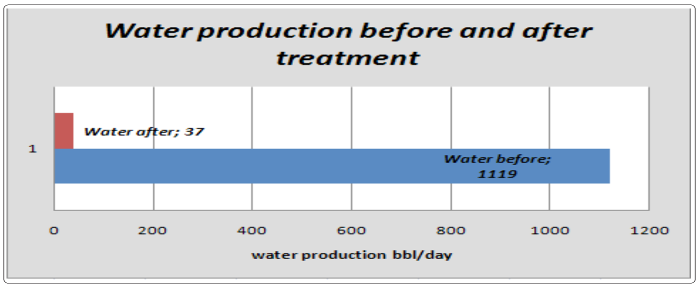

Figure 6: Water productions at optimum concentration

Analysis

The optimum water cut obtained was 24% at this water cut polymer concentration used was 0.7 (7000 ppm), the highest incremental in oil production was 499 bbl/day achieved at 0.2 polymer concentration (2000 ppm). At 0.3 polymer concentration (3000 ppm) the total money saved was 11938 $/day and this was the optimum.

After analyzing those figures the optimum concentration suggested to be use is 0.3 (3000ppm) which gives the heights total money saved 11938 $/day. 75% and 230 bbl/day as incremental oil production.

Well Y

Diagnose: water channelling problem.

Treatment: Water channelling is one of the problems that polymer–gel injection can solve, so the well data is applied to the model and thus the results obtained using different concentrations.

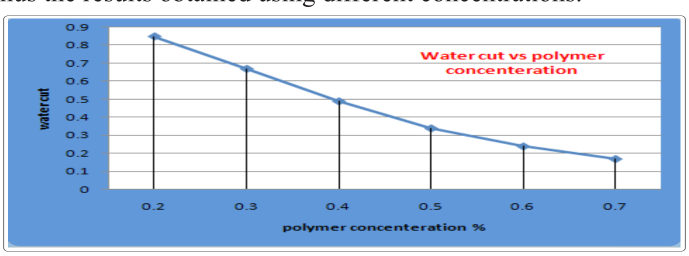

Figure 7: Water cut vs. polymer concentration

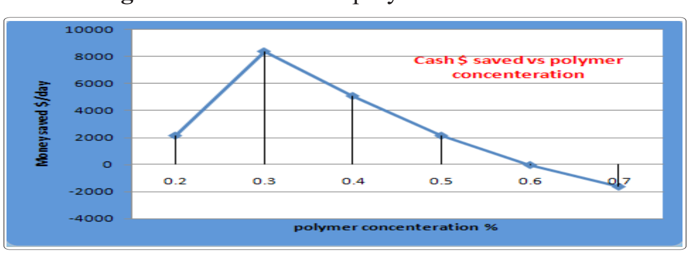

Figure 8: Money saved vs. polymer concentration

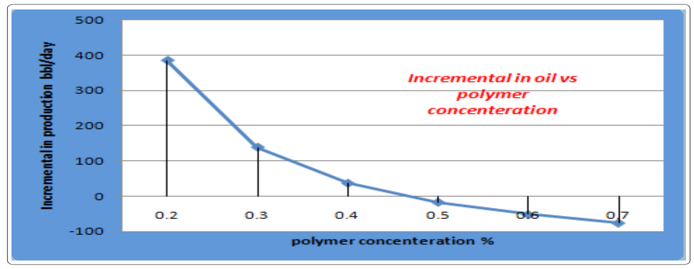

Figure 9: Incremental in oil vs. concentration

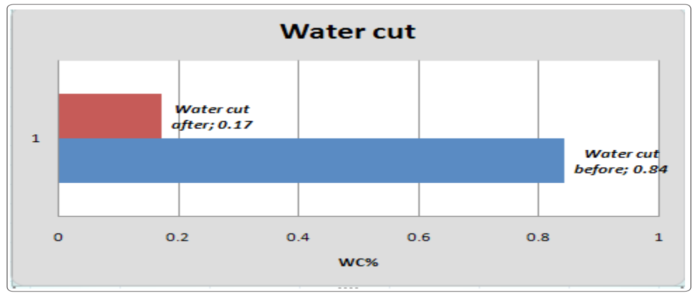

Figure 10: Water cut at optimum concentration

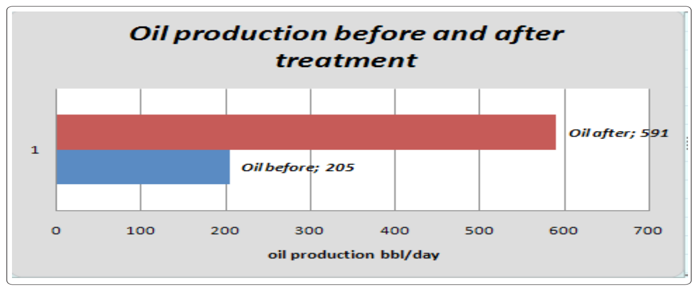

Figure 11: Oil productions at optimum concentration

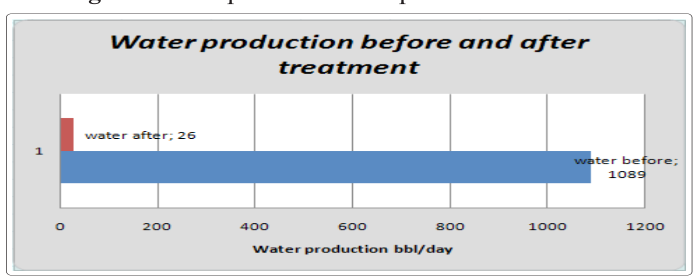

Figure 12: Water productions at optimum concentration

Analysis

The optimum water cut obtained was 17% at this water cut polymer concentration used was 0.7 (7000 ppm), the highest incremental in oil production was 385.6 bbl/day achieved at 0.2 polymer concentration (2000 ppm). At 0.3 polymer concentration (3000 ppm) the total money saved was 8386.4 $/day and this was the optimum.

After analyzing those figures the optimum concentration suggested to be use is 0.3 (3000ppm) which gives the heights total money saved 8386.4 $/day. 67% water cut and 139.4 bbl/day as incremental oil production.

Well Z

Diagnose: water conning problem.

Treatment: Water coning is one of the problems that polymer – gel injection can solve, so the well data is applied to the model and thus the results obtained using different concentrations.

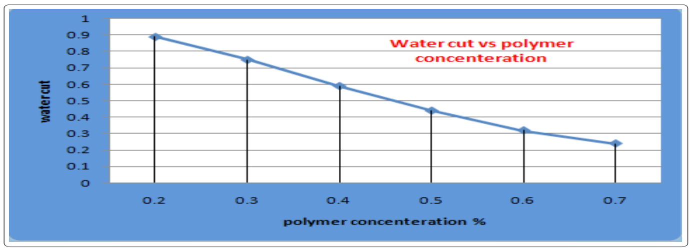

Figure 13: Water cut vs. polymer concentration

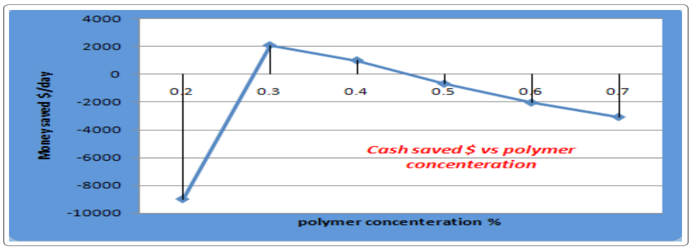

Figure 14: Money saved vs. polymer concentration

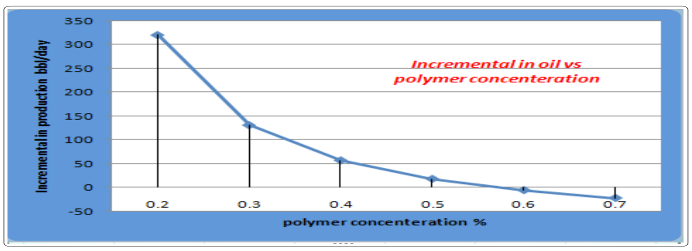

Figure 15: Incremental in oil production vs. polymer concentration

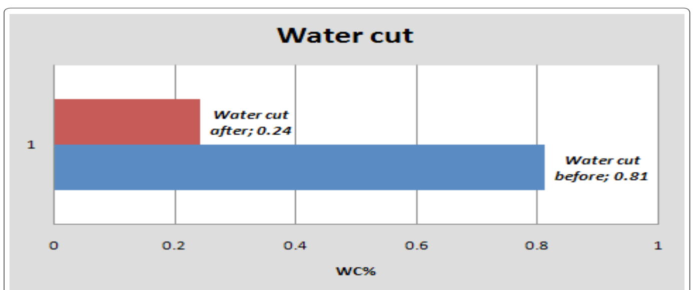

Figure 16: Water cut at optimum concentration

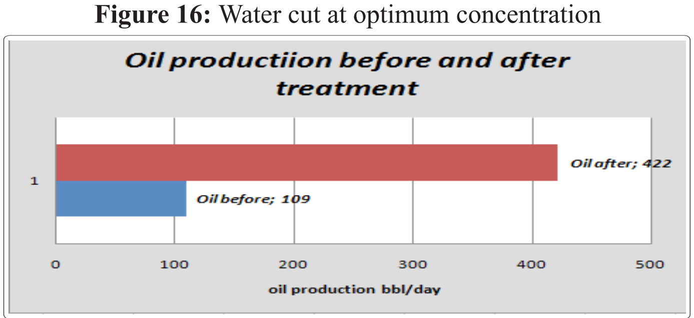

Figure 17: Oil production at optimum concentration

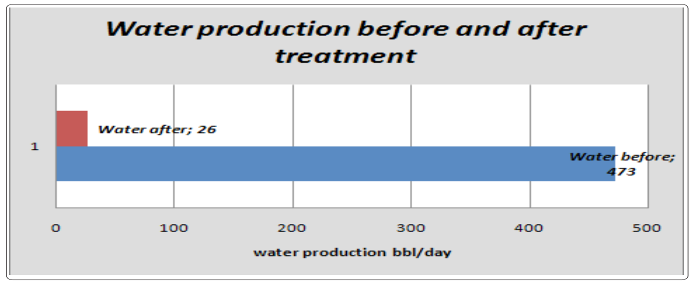

Figure 18: Water production at optimum concentration

Analysis

The optimum water cut obtained was 24% at this water cut polymer concentration used was 0.7 (7000 ppm), the highest incremental in oil production was 321.9 bbl/day achieved at 0.2 polymer concentration (2000 ppm). At 0.3 polymer concentration (3000 ppm) the total money saved was 2097.5 $/day and this was the optimum.

After analyzing those figures the optimum concentration suggested to be use is 0.3 (3000ppm) which gives the heights total money saved 2097.5 $/day. 75% water cut and 131.2 bbl/day as incremental oil production.

Table 3: After treatment results at their optimum concentrations

Well Name	Water cut%		Money saved($/d)	Incremental oil(bbl/d)
	Before	After		
Well X	0.91	0.24	11938	499
Well Y	0.84	0.17	8386.4	591.3
Well Z	0.81	0.24	2097.5	432.5

Conclusion

1. Water production considered as one of the most major problems in oil industry in general.
2. The equations predicted that the determination of the water permeability reduction after treatment.
3. A model that constructed illustrated the water cut percentage before and after treatment.
4. HPAMs polymer with cross linkers considers as the most effective chemical solutions in reducing water cut percentage.
5. Minimum polymer concentration (0.5-0.3) % is preferable to be use in the gel solution which gives optimum results.
6. Using polymer-gel is not only reducing the water production but it also increase oil production.
7. From researching in the literature we find that to get maximum benefit from Gel as blocking agent behaviour the suitable conditions are:

a. Treatment should be aqueous.
b. Density of treatment should greater than water density and low viscosity to go directly to water zone.

Recommendation

1. According to our results there is a great chance for chemical treatments (polymer-gel) , so we recommend to a plicate.
2. Core flood study must take for further investigation to obtain a sufficient set of data and predict more accurate equations.
3. Study the effect of other parameters such as salinity and reservoir temperature on permeability reduction rather than the effect of polymer concentration only.

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