

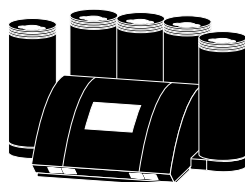


Application Note

## Understanding the phase separation behaviour of microemulsions for enhanced oil recovery processes

*Microemulsion mixtures are commonly used for enhanced oil recovery (EOR) processes due to their high crude oil extraction efficiency. Generally, such mixtures consist of a thermodynamically stable dispersion of crude oil, surfactant, and water or brine. The phase behaviour of the mixture changes from Winsor I to Winsor II by the way of Winsor III when adjusting temperature, salinity, and pressure. The Winsor III state is the most desirable during the EOR process. The dispersion stability analysis system MultiScan MS20 from DataPhysics Instruments (Fig. 2) is a compact and versatile measuring device for the optical stability and aging analysis of a variety of multi-phase dispersions. The phase behaviour of a crude oil, surfactant, and water mixture will be presented in this application note.*

Measurement device  
MultiScan MS20



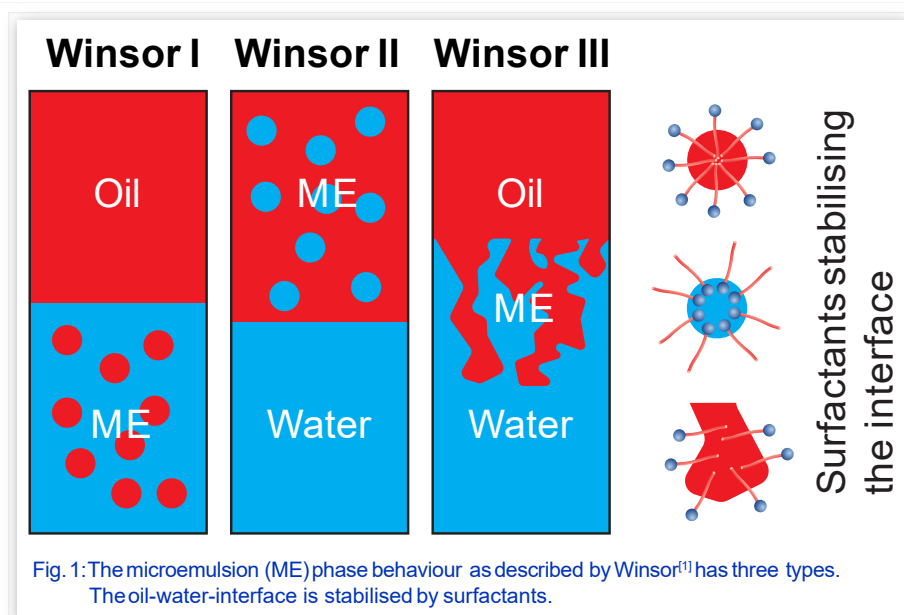
Measurement method  
Optical dispersion stability analysis

Samples  
Crude oil  
Surfactant  
Water  
Microemulsion

Measured quantities  
Stability analysis  
Destabilisation kinetics

Environmental conditions  
Temperature: 70 °C

Industries  
Enhanced oil recovery (EOR)



## Introduction

In order to extract crude oil from increasingly difficult-to-access reservoirs, a multitude of new extraction methods have been developed for enhanced oil recovery (EOR) processes. A very successful and popular technique is based on the recovery of crude oil using a water-surfactant-mixture.

A common classification of such mixtures into three different types was established by P.A. Winsor<sup>[1]</sup> (see Fig. 1). In a Winsor I mixture, oil droplets are emulsified in the water phase. In a Winsor II mixture, water droplets are emulsified inside the oil phase. Finally, in a Winsor III mixture, a bicontinuous phase of a network of water and oil is stabilised by surfactants.

All three types are thermodynamically stable. By adjusting the temperature and salinity of the water phase the system alternates between the three different types. For enhanced oil recovery processes, the Winsor III phase is the most desirable, as it has the lowest interfacial tension ( $10^{-2} \dots 10^{-4}$  mN/m) and the surfactants are used most efficiently. Hence, the phase behaviour is extensively researched to find the right surfactants, salinity and temperature to generate ideal extraction conditions<sup>[2][3][4]</sup>.

## Technique and Method

The dispersion stability analysis system MultiScan MS20 (Fig. 2) from DataPhysics Instruments is a measuring device for the automatic, optical stability and aging analysis of liquid dispersions. It therefore allows a comprehensive characterisation of time- and temperature-dependent destabilisation mechanisms in multi-phase mixtures.

The MultiScan MS20 consists of a base unit and up to six measuring chambers. The sample chambers, or ScanTowers, of the MultiScan MS20 can be individually controlled and operated at different temperatures and temperature curves between



$-10^{\circ}\text{C}$  and  $80^{\circ}\text{C}$ . With its matching software MSC, MultiScan MS20 is an ideal partner for stability analyses, as even the slightest changes within dispersions can be detected and evaluated. Thus, the MultiScan MS20 enables an objective and reliable analysis of the dispersion stability as well as conclusions on possible destabilisation mechanisms.



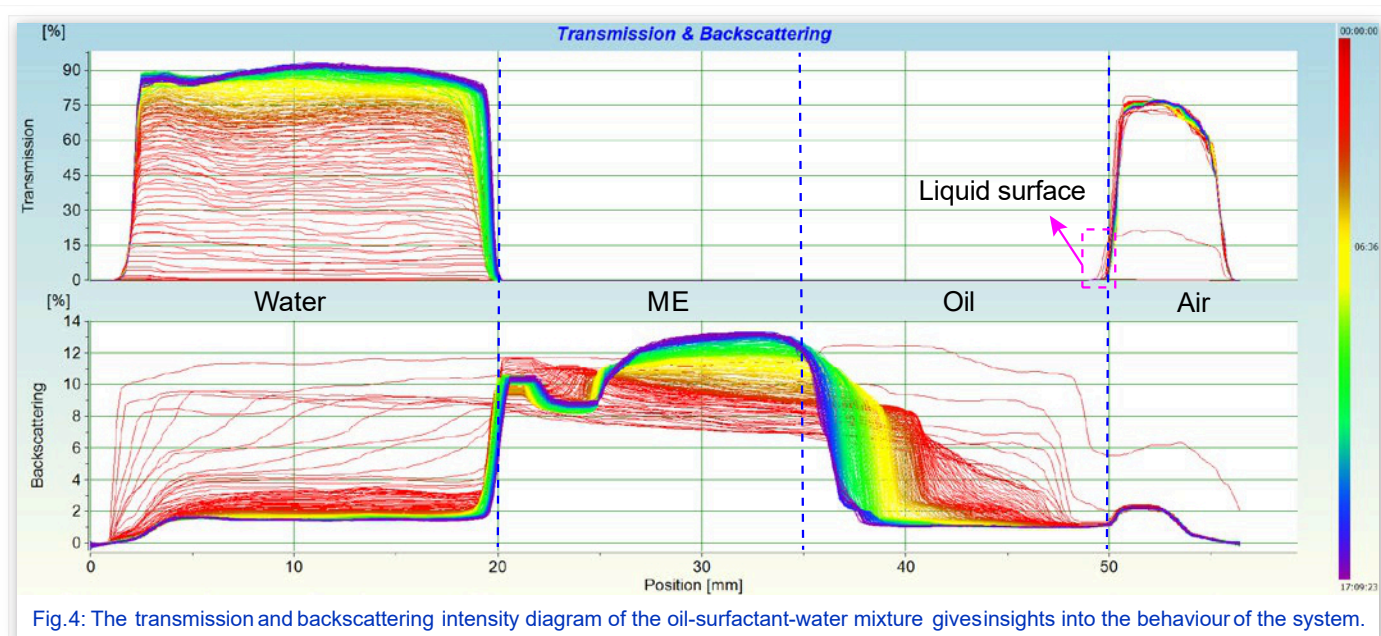


Fig.4: The transmission and backscattering intensity diagram of the oil-surfactant-water mixture gives insights into the behaviour of the system.

### Experiment

20 ml of a crude oil and water mixture was poured in a transparent glass vial. After adding a certain amount of surfactant, the mixture was stirred at room temperature, then heated and measured at a temperature of 70 °C every three minutes for 17 hours. The measured zone was between 0 mm (bottom of the vial) and 57 mm (top of the vial). Fig. 3 shows the sample vial at the end of the measurement.

### Results and Discussion

Fig. 4 shows transmission and backscattering intensities against the position within the oil-surfactant-water mixture. The colour-coding of the curves indicates the time at which the measurements were recorded, from red (start of the experiment, T = 0 s) to purple (end of experiment, T = 17h). Every curve represents one individual measurement.

The transmission diagram (Fig. 4, top) shows a clearly time-dependent as well as position-dependent change of the signal, which increased in the bottom layer (between 1 mm and 20 mm). This indicates that emulsified oil-surfactant drops are coalescing and migrating upwards. It is mainly water which remains in the bottom layer.

During the experiment, the middle and upper layers (20 mm to 50 mm) show a transmission intensity of 0%. This means that the light cannot penetrate the liquid, suggesting that

here, we can find either crude oil or a oil-surfactant-water mixture (also called 'microemulsion phase', see Fig. 1). A closer look at the backscattering values is needed to characterise the mixture further.

The backscattering intensity diagram in Fig. 4 (bottom) shows a decrease of backscattering intensities along the entire vial height in the first 30 minutes, which means that coalescence occurred.

Consistent with the interpretation of the measured transmission values and the characterisation developed by Winsor (Fig. 1), the backscattering intensity decreased in the bottom layer of the vial (between 1 mm to 20 mm) as well as in the top layer (between 35 mm to 50 mm), while it increased in the middle layer (between

20 mm and 35 mm) after the first 30 minutes. This pattern indicates that a phase separation takes place and a microemulsion was formed with a thickness of around 15 mm in the middle layer (between 20 mm and 35 mm) of the vial. This is consistent with the appearance of the vial at the end of the measurement (Fig. 3) and it can be concluded that a Winsor III microemulsion was formed.

### Clarification kinetics in the bottom layer

Calculated with the respective function of the MSC software, the peak area change rate of the bottom layer (between 1 mm and 20 mm) can be analysed. Fig. 5 shows that there is no change of transmission intensity in the first 30 minutes, while fast changes occur in the backscattering intensity

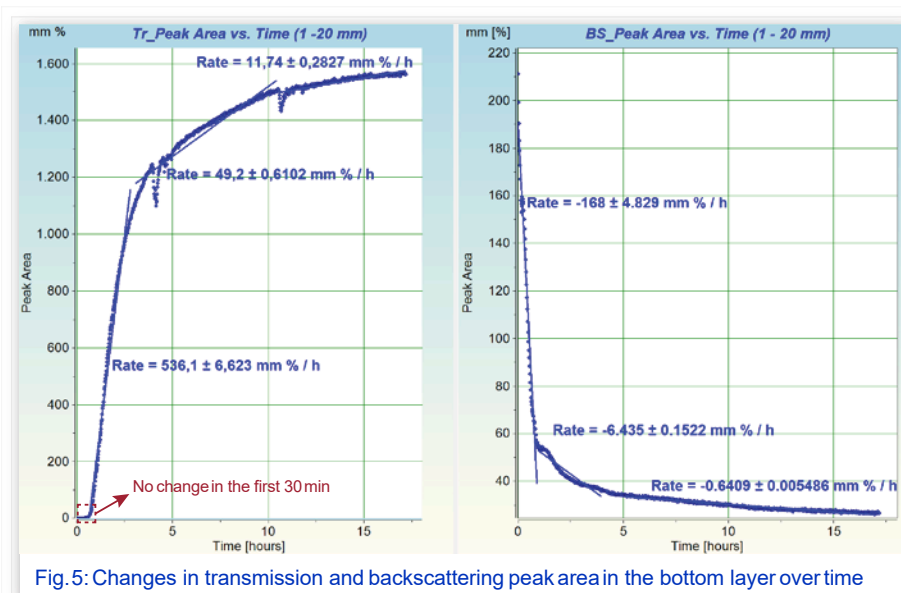


Fig. 5: Changes in transmission and backscattering peak area in the bottom layer over time

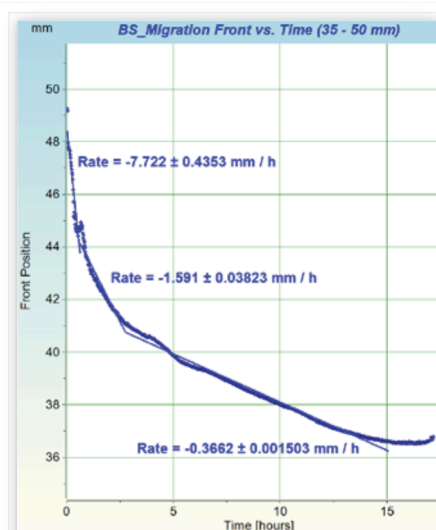


Fig. 6: Changes of the migration front in the top layer over time

with a rate of 168mm%/h. Again, this observation confirms that a coalescence process is predominant. Besides, the peak area change rate of both transmission and backscattering in the first 10 hours are much higher than in the last 7 hours, which reveals that most of the microemulsion drops have coalesced and migrated into the middle and top layer in the first 10 hours.

#### Clarification kinetics in the top layer

Fig. 6 shows an evaluation of the top layer (35mm to 50mm), using the 'migration front method' of the MSC-software. The graph reveals that the backscattering intensity decreases over time in the top layer, which suggests a clarification process in this area. As displayed in Fig. 6, the front of emulsion drops decreases remarkably in the first 2.5 hours in this layer, due to the coalescence and migration of the drops. Almost all emulsion drops have migrated to the middle layer after around 15 hours.

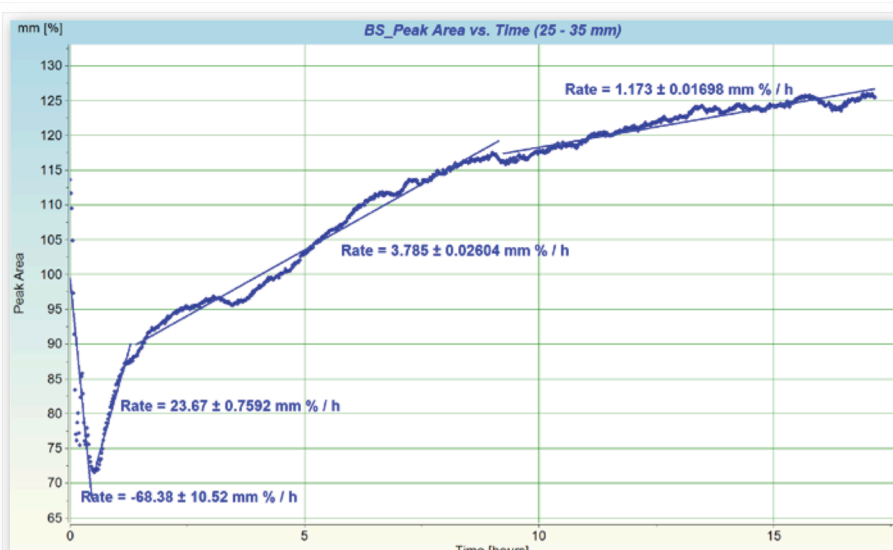


Fig. 7: Changes of the peak area inside the middle layer overtime

#### Stability in the middle layer

The stability of the microemulsion phase in the middle layer (between 25 mm and 35 mm) was analysed with the 'peak area method' of the MSC-software, determining the change rates as displayed in Fig. 7. In consistency with the aforementioned results, the peak area decreased dramatically with a change rate of -68.38 mm%/h in the first 30 minutes, indicating the coalescence of the emulsion drops. Hereafter, a notable increase of the peak area was observed, demonstrating that more and more emulsion drops migrated to the middle layer. The whole system is moving towards an equilibrium.

#### Summary

Using the MS20 stability analysis system and its corresponding MSC software, an easy and fast way to study the stability and phase behaviour of mixtures made of crude oil, surfactant and water, could be demonstrated. Such studies enable researchers to

quantify stability issues, and thus enables the development of efficient techniques for EOR processes.

#### References

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- [2] Bera A., Mandal A. *Microemulsions: a novel approach to enhanced oil recovery: a review*. J. Petrol. Explor. Prod. Technol. 2015, 5, 255–268. DOI: 10.1007/s13202-014-0139-5
- [3] Pal N., Kumar S., Bera A., Mandal A. *Phase behaviour and characterization of microemulsion stabilized by a novel synthesized surfactant: Implications for enhanced oil recovery*. Fuel, 2019, 235, 995-1009. DOI: 10.1016/j.fuel.2018.08.100
- [4] Xu L., Han M., Cao D. Q., Wang J. X. *Study on dynamic interfacial tension behaviors in surfactant selection for improving oil production*. J. Petrol. Sci. Eng. 2022, 209, 109978. DOI: 10.1016/j.petrol.2021.109978

We will find a tailor-made solution for your surface science use case and will be pleased to provide you with an obligation-free quotation for the system that fits your needs. For more information please contact us.

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