Control of surface properties and efficiency of some antifoaming agents used in beet sugar manufacturing

Abdelfattah Bensouissi, Barbara Rogé and Mohamed Mathlouthi

In a sugar factory, foam formation occurs at all stages of processing, beginning with beet washing. In this work different antifoaming agents were compared by studying their mechanism of action and optimizing the most efficient doses. The relative efficacy of six samples of antifoaming agents was determined as a function of concentration and temperature. It was shown that the efficiency increases with concentration and exhibits a threshold. The effect of temperature resides in the need that antifoaming agents are added at a temperature above the turbidity (cloud point). Likewise, antifoaming agents were classified as a function of their hydrophobicity and efficiency at normal temperature. It was shown that efficiency increases with hydrophobicity. The more efficient an antifoaming agent, the slower its adsorption at the air/liquid interface. A mechanism of trapping of juice surface-active molecules by antifoaming agents is proposed.

Finally, adsorption kinetics were studied at high temperature for antifoaming agents which were quickly adsorbed at normal temperature. It was found that increasing temperature facilitates the adsorption of antifoaming agents at the interface. Such an adsorption is the more important the more efficient the antifoaming agents at normal temperature. A decrease in the activation energy for the adsorption of antifoaming agents from subsurface to interface was proposed as a possible explanation of antifoaming agent behavior at interfaces.

Key words: antifoaming agents, surface properties, beet sugar manufacture

1 Introduction

In sugar factories, foam formation occurs at all stages of the processing, especially during juice extraction. This is due to the surface active molecules (saponins, proteins, peptides, etc, ...) extracted from beet on the one hand, and to the agitation and pumping which incorporates air into the juice on the other hand [1]. Different drawbacks are linked to foam formation, such as extractor clogging, decrease in sugar extraction yield, overflow in tanks, which induces appreciable sugar loss [2]. To prevent foam formation, the general rule is the injection of antifoam products. Different patents describe these types of product [3–8] which are generally composed of copolymers of ethylene and propylene oxides (70%) and mineral oil (30%). The ratio of ethylene/propylene polymers varies with antifoam agents and their applications. In the mean time, the polymer may be esterified or not with fatty acids or polyols. Other minor constituents may also be found in the agents such as colorants or emulsifiers and so on. To summarize, it may be stated that antifoaming agents used in sugar factories have complex formulas, most of time protected by patents, and their composition is difficult to know in detail. Despite the lack of information, the users in factories are more or less obliged to use commercial agents and their reaction in the case of foam increases is to increase the dose of antifoaming agent or to use new expensive agents recommended by suppliers. However, the tendency now is to use fewer processing aids, and if possible those which are environmentally friendly.

In this paper, results of an optimization study of antifoam dose for six commercial agents used in sugarbeet extractors are reported. Surface properties and cloud points (see 2.4.1) for the six studied antifoams were also determined and a mechanism of action of the antifoams is proposed based on the comparison of their properties and efficacy.

2 Material and methods

2.1 Foaming control solution

A raw juice free from antifoams was used as the reference material for foaming studies. The juice (16% RDS) was sampled during 2005 beet sugar campaign at a partner factory and stored at 4 °C after adding azide as a preservative.

2.2 Antifoam samples

The commercial antifoam samples used in this work were supplied by the 2 major suppliers of technical aids to the French beet sugar factories. They were named AM1, AM2, AM3, AM4, AM5 and AM6. For all the antifoams used, a sample of the polymers constituting it was supplied. The following information on the composition of antifoams was available:

- AM1: Ethylene and propylene copolymer oxides esterified with a vegetable fatty acid mixed with mineral oil;
- AM2: Polyether-polyol esterified with a vegetable fatty acid mixed with mineral oil;
- AM3: Ethylene-propylene copolymer oxide esterified with fatty acid mixed with mineral oil;
- AM4: Copolymers esterified with a plant fatty acid mixed with vegetable oil and mineral oil;
- AM5: Copolymers of ethylene and propylene oxides esterified with vegetable fatty acid mixed with mineral oil;
- AM6: Mixture of polyalkoxyether and mineral oil.

2.3 Method of control of antifoam efficiency

2.3.1 Foaming at ambient temperature

Experiments of foaming at ambient temperature (22 ± 2 °C) in the presence or not of antifoam were performed using a Foam Scan apparatus (IT Concept, Lyon, France). Foam was obtained by nitrogen bubbling in the foaming solution. A constant flow of nitrogen (15 mL/min) was fed through a sintered glass bottom of a column (L = 30 cm; d = 3 cm) containing 15 mL of juice. The column is lighted with a white light source on one side and foam pictures were taken with a CCD camera on the opposite side. Pictures were taken each second, digitized and treated by software to give the variation of foam volume as a function of time. Treatment of data is similar to that of the Foam Scan.

2.3.3 Relative efficacy of antifoams

The relative efficacy (RE) of antifoams is expressed in terms of the percentage of foam inhibited by the addition of a certain concentration of added antifoam. It is calculated as follows:

\[ RE = \frac{V_{\text{max,lp}} - V_{\text{max,af}}}{V_{\text{max,lp}}} \]

where \( V_{\text{max,lp}} \) is the maximum volume of foam obtained in juice without added antifoam agents and \( V_{\text{max,af}} \) is the maximum volume of foam obtained in juice with added antifoam at a given concentration in the same conditions of temperature and foaming.

2.4 Method of control of antifoam surface properties

2.4.1 Cloud points

The cloud point of an antifoam is, by definition, the temperature at which solubility is reversed. At a value below the cloud point, the antifoam is water soluble. Above this temperature it becomes insoluble. At a molecular level, this change in solubility is due to the dehydration of polar heads. Such a breakage of low energy bonds between water and polar groups results in micelle formation. Hydrophobic interactions occur between the surface active molecules, water is repelled and the product remains insoluble. Micelle formation corresponds to a minimum free energy of the system.

Cloud points of copolymers corresponding to the formula of the different antifoams were determined by the measurement of absorbance at 420 nm at temperatures varied from 20 to 90 °C. Measurements were made for solutions containing 1 mL of copolymer and 99 mL of doubly distilled water. Absorbance was measured with a Shimadzu UV-2101 spectrophotometer. Sample temperature was controlled with a Polyscience 9110-RH thermostated bath. Rate of increase of temperature was 2 K/min.

2.4.2 Contact angles

Measurement of contact angles of antifoam samples with a hydrophobic surface (Teflon) was made at 22 °C. The aim of such measurements was to classify antifoams on the basis of their hydrophobicity. This measurement consists in spreading a drop of antifoam on a perfectly smooth hydrophobic surface. The more the sample has affinity for the hydrophobic surface the lower the angle between the tangent to the first contact angle of the drop and the horizontal plane. Measurements were made with a drop tensiometer (IT Concept, Lyon, France). A small drop (2 µL) of antifoam at the end of a syringe is deposited on a Teflon surface. A CCD camera takes pictures each second and transfers them to a computer with appropriate software (Old drop, IT Concept), which determines contact angles (θ) from image analysis.
2.4.3 Kinetics of adsorption of antifoam at the air/water interface

Measurement of surface tension was made using a bubble tensiometer (IT Concept, Lyon). A description of the method is reported by Benjamins et al. [9]. A bubble of 2 mL volume is formed at the extremity of a syringe in the middle of a sample (20 mL) of antifoam. The shape of the bubble is controlled with a CCD camera and images are analyzed with a dedicated software (Old drop, IT Concept). Surface tension is determined from the analysis of the bubble profile by application of the Laplace equation:

\[
\frac{1}{x} \cdot \frac{dx}{x} \cdot (x - \sin \theta) = 2 \cdot b - c \cdot z
\]

where \(x\) and \(z\) are coordinates of different points in the bubble profile in a Cartesian system, \(\theta\) is the angle of the tangent to the bubble profile with \(x\) axis and \(b\) is curvature radius at the bubble apex (Figs. 1 and 2); \(c\) is the capillary constant \((c = g \cdot \Delta \rho / \sigma)\) with \(\Delta \rho\) the difference in density between juice and air; \(g\) is the gravitational acceleration and \(\sigma\) the interfacial tension. A 5 mL sample of raw juice is mixed with 20 mL/L of antifoam and used in surface tension measurement. Surface tension is measured each 30 s after bubble formation. To eliminate any suspended matter in the juice, 2 bubbles are formed and destroyed prior to data collection. Another method of elimination of suspended matter applied is the centrifugation of samples during 10 min at 10,000 min\(^{-1}\) at ambient temperature. Analysis was performed at 22 \(^\circ\)C \(\pm\) 0.5 \(^\circ\)C in a first series of determinations for all antifoam samples and at 70 \(^\circ\)C in a second series of measurements for antifoams AM4, AM5, and AM6. Control of temperature was obtained as shown on Figure 2 with circulation of water from a thermostatted bath. Densities of juice samples were measured with an Anton Paar DMA 4500/5000 and the values were 1.058 and 1.033 respectively at 22 \(^\circ\)C and 70 \(^\circ\)C.

3 Results and discussion

3.1 Efficacy of antifoams as a function of concentration

3.1.1 RE at ambient temperature

Relative efficacy was determined for all six samples of antifoams at ambient temperature in the range of concentrations from 0 to 100 mL/L with the aim of determining the optimal concentration. Results are reported in Figure 3. A difference in efficiency is observed as concentration of antifoam is varied. For example a dose of 10 mL/L of AM1 permits elimination of 99% of foam while only 20% are eliminated by the use of the same concentration of AM6. Figure 3 also shows that for a certain concentration, which is specific for each antifoam, it is useless to increase the dose of antifoam as no additional efficacy (foam inhibition) is obtained.

3.1.2 RE at high temperature

Three antifoams (AM4, AM5, AM6) found relatively less efficient at normal temperature were analyzed at 70 \(^\circ\)C for 3 concentrations: 10, 50 and 100 mL/L as summarized in Table 1. It is shown in Table 1 that the increase of temperature from 22 to 70 \(^\circ\)C noticeably improves the efficiency of AM4 and AM5. Therefore, a concentration of 10 mL/L yields improvements of 25.68% and 24% respectively for the AM4 and AM5 samples. With 50 and 100 mL/L, improvement of efficiency is less remarkable (2.13% for AM4 and 9.94% for AM5). It should also be noticed that at 70 \(^\circ\)C foam is formed by shearing while it is formed by bubbling at normal temperature.

<table>
<thead>
<tr>
<th>Antifoam</th>
<th>Concentration (mL/L)</th>
<th>RE at 22 ± 2 (^\circ)C (%)</th>
<th>RE at 70 ± 2 (^\circ)C (%)</th>
<th>RE at 85 ± 2 (^\circ)C (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM4</td>
<td>10</td>
<td>42.32 ± 2</td>
<td>68 ± 2</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>80.12 ± 1</td>
<td>82.25 ± 1</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>81.06 ± 1</td>
<td>84 ± 1</td>
<td>–</td>
</tr>
<tr>
<td>AM5</td>
<td>10</td>
<td>32.18 ± 2</td>
<td>56.2 ± 2</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>60.21 ± 1.5</td>
<td>70.15 ± 1</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>65.26 ± 3</td>
<td>76.32 ± 1</td>
<td>–</td>
</tr>
<tr>
<td>AM6</td>
<td>10</td>
<td>17.01 ± 3</td>
<td>43.1 ± 2</td>
<td>55.81 ± 2</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>38.31 ± 2</td>
<td>55.8 ± 1.5</td>
<td>75.64 ± 1</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>48.61 ± 2</td>
<td>60 ± 2</td>
<td>79.74 ± 1.5</td>
</tr>
</tbody>
</table>

* It should be noted that at 70 \(^\circ\)C foam is formed by shearing while it is formed by bubbling at normal temperature.

For AM6, increase in efficacy is important as temperature is increased from 22 to 70 \(^\circ\)C. However, the values obtained at 70 \(^\circ\)C are not satisfactory as compared to the AM4 and AM5 antifoams. For this it was necessary for AM6 to increase the temperature to 85 \(^\circ\)C.
3.1.3 Antifoam efficacy as a function of concentration after numerous cycles of foaming

The efficacy of AM6 after 3 successive cycles of foaming was determined at 70 and 85 °C. A foaming cycle consists in 300 s of shearing (pump circulation) to form the foam followed by 300 s of rest to achieve the complete drainage of the formed foam. Four concentrations of antifoam were tested (0; 10; 50; 100 mL/L) at 70 °C and 85 °C. Results are reported in Figures 5 and 6. It was observed that in the absence of antifoam the foam volume increases after each cycle of foaming. This may be due to the fact that the shearing in the second and third cycles creates more and more interfaces between air and liquid as schematically represented in Figure 4. The newly formed interface is less concentrated in surface active molecules than that before second or third cycle of shearing. To obtain a homogeneous repartition of foaming surface-active molecules at the interface, an inflow of foaming surface-active monomers from the region surrounding the interfaces is necessary. Such a contribution of monomers ruptures the equilibrium between micellar and monomeric forms of antifoam in the solution [10]. Therefore micelles of foaming surface active molecules constitute a reservoir feeding the interface. If interfaces are regularly fed by monomers, there is more and more foam after second and third shearing cycles (Fig. 4).

It may be observed in Figure 5 that for the first cycle of foaming, an increased antifoam concentration gradually increases the efficacy (foam volume reduction). However, in the second and third cycles, the maximum foam volume obtained with 50 mL/L of AM6 at 70 °C is situated above that obtained with 10 mL/L in the first cycle. This phenomenon was not observed when the temperature was raised to 85 °C (Fig. 6).

3.2 Efficacy of antifoams as a function of surface properties

3.2.1 Cloud points and antifoam efficacy

Cloud points of copolymers corresponding to the six antifoams were measured. Results are summarized in Figure 7. Two copolymers corresponding to antifoams AM2 and AM4 were termed AM2-A, AM2-B and AM4-A and AM4-B, respectively. Observation of Figure 7 shows that cloud points for copolymers corresponding to antifoams AM1, AM2 and AM3 which are most efficient at low temperature, are situated at lower temperatures than those corresponding to AM4, AM5 or AM6. For this latter antifoam (AM6), it was not possible to obtain a sample of the copolymer from the supplier. Therefore, the cloud point reported in Figure 7 was measured on the whole AM6 agent.

For AM6, Figure 7 and Table 1 show that this antifoam does not show any cloud at ambient temperature, which gives a relatively low efficacy (RE = 38.31 ± 2% at 50 mL/L). At 70 °C, AM6 starts forming a slight cloud. Its efficacy is improved (RE = 55.8 ± 1.5% at 50 mL/L). At a temperature of 85 °C, its cloud point is reached and efficacy is at its maximum (RE = 75.64 ± 1% at 50 mL/L). On the other hand, as already mentioned, AM6 shows a loss of efficacy after repeated cycles of foaming at 70 °C for a concentration of 50 mL/L (Fig. 5). At 85 °C, for the same concentration, efficacy loss is not observed (Fig. 6). This is explained by the inhibition of transfer of juice surface active molecules to the freshly formed air/liquid interfaces. Two hypotheses may be proposed in this case: either the
antifoam prevents the disintegration of juice surface active micelles or it inhibits their diffusion from bulk solution to the vicinity of interface (Fig. 4).

3.2.2 Antifoam hydrophobicity and efficacy

As antifoams are more efficient when they form clouds (micelles), their cloud point temperatures and efficacies vary with their composition. The property responsible for such variability is very likely the degree of hydrophobicity of antifoam which may be evaluated by HLB (Hydrophilic-Lipophilic Balance) or eventually the contact angle with a hydrophobic surface. A classification of the studied antifoams is proposed based on θ, the contact angle measured as described earlier (Table 2). Comparison of antifoam hydrophobicity and foam inhibition efficacy shows that the more the antifoam is hydrophobic, the higher its relative efficacy.

3.3 Adsorption of antifoams at air/liquid interface and mechanism of action

3.3.1 At ambient temperature

The kinetics of antifoam adsorption at the interface was measured at ambient temperature. Air/liquid interface was obtained by the formation of a bubble of controlled size in the solution composed of raw juice mixed with 20 mL/L of antifoam. The adsorption kinetics were recorded each second for 30 s just after the formation of the bubble. Such a duration (30 s) corresponds to the formation of the first adsorption layers of tensioactive molecules (from the juice and or the antifoam) at the interface. The results are reported in Figure 8.

It may be observed that surface tension decreases gradually as a function of time for all samples composed of raw juice without and with 20 mL/L of each of the antifoams (Fig. 8). To assert the pertinence of the measurement of surface tension, it should be recalled that the measured value results from 2 forces acting on the bubble: its mass and the surface tension. Mass tends to lengthen the bubble and surface tension, on the contrary, tends to maintain a spherical shape. Whereas mass is constant, surface tension varies with the quantity of adsorbed molecules. For juice free from added antifoam, the value of surface tension is around 63 mN/m, slightly higher than that reported by VanHook and Biggious [2]. This might have been due to the preparation of juice sample which was centrifuged to eliminate suspended matter which may influence the measurement of surface tension. On the other hand, the slope of surface tension decrease as a function of time is much weaker in the case of juice without antifoam agent. Only juice surface active molecules are adsorbed. In the case of adsorption of both juice and antifoam surfactants, the slope changes and seems characteristic of each antifoam (Fig. 8).

As the variation of surface tension as a function of time accounts for the adsorption on the bubble wall of the surface active molecules, the slopes of the tangents at the origin of the curves represented in Figure 8 were determined and reported in Table 3. Comparison of surface tension curves slopes to the values of relative efficacies of the six antifoam samples at ambient temperature shows that the slower the adsorption of antifoam at the air/liquid interface, the higher the efficacy of foam inhibition (Table 3). This means that the efficacy of the antifoam is linked to its staying for a longer time in the solution rather than rapidly reaching the air/solution interface. This suggests a possible mechanism of action, which consists in trapping the surface active molecules from raw juice by the antifoam and preventing them from forming foam.

![Table 2: Average contact angle of the studied antifoams](image)

<table>
<thead>
<tr>
<th>Antifoam</th>
<th>Average contact angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM1</td>
<td>46.7 ± 1</td>
</tr>
<tr>
<td>AM2</td>
<td>49.2 ± 0.5</td>
</tr>
<tr>
<td>AM3</td>
<td>59.6 ± 0.5</td>
</tr>
<tr>
<td>AM4</td>
<td>60.3 ± 0.3</td>
</tr>
<tr>
<td>AM5</td>
<td>65.9 ± 0.2</td>
</tr>
<tr>
<td>AM6</td>
<td>66.6 ± 0.4</td>
</tr>
</tbody>
</table>

![Table 3: Slopes of tangents at the origin of curves representing surface tension evolution and relative efficacies of the different antifoam samples](image)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Slope of tangent at origin of surface tension curve</th>
<th>Relative efficacy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure extraction juice</td>
<td>-0.210</td>
<td>-</td>
</tr>
<tr>
<td>AM1</td>
<td>-0.626</td>
<td>97.82</td>
</tr>
<tr>
<td>AM2</td>
<td>-0.665</td>
<td>65.42</td>
</tr>
<tr>
<td>AM3</td>
<td>-0.669</td>
<td>68.58</td>
</tr>
<tr>
<td>AM4</td>
<td>-0.749</td>
<td>55.97</td>
</tr>
<tr>
<td>AM5</td>
<td>-0.887</td>
<td>48.40</td>
</tr>
<tr>
<td>AM6</td>
<td>-0.957</td>
<td>25.89</td>
</tr>
</tbody>
</table>

3.3.2 At high temperature

The kinetics of the adsorption of antifoams (AM4, AM5 and AM6) which are less efficient at ambient temperature was followed at 70 °C as well as for juice free from antifoam. The results are reported together with that obtained at 22 °C in Figure 9. It may be observed that for the juice free from antifoam, the surface tension decreases more rapidly at 70 °C as at 22 °C. This is very likely due to the effect of temperature on the diffusion of surface active molecules as well as on the activation energy of adsorption at the interface which is reduced as temperature is increased. Moreover, Figure 9 also shows that the difference in surface tension between the values obtained at the 2 temperatures is much higher in the absence of antifoam as it is in their presence. This feature is also interpreted as an argument in favor of the trapping of surface active molecules from raw juice by antifoams which act as inhibitors of foam promotion. In the case of samples containing antifoam, it should be noticed that the higher the efficiency of the antifoam, the larger the difference between curves recorded at 70 and 22 °C. It should
be recalled that antifoams are in the form of micelles at 70 °C and their behavior at air/liquid interface is described as spreading rather than adsorption. A large difference between the 2 curves denotes an easier spreading of antifoam on the film of foam, which leads to a more important de-foaming effect.

4 Conclusion

From the experimental work presented in this paper, it can be concluded that:

– The efficacy of antifoams, apart from their composition, mainly depends on 2 parameters, concentration which shows a threshold value and temperature which has to reach the cloud point of the antifoam.

– Depending on their localization in the foaming system, antifoams seem to proceed according to 2 different and complementary mechanisms of action:

I) In solution: antifoams act to prevent foam formation. This is achieved by the delaying of surface active molecules adsorption at air/liquid interface. The more the antifoam is hydrophobic, the higher this type of antifoaming effect.

II) Near the interface: Antifoams exert a de-foaming effect by spreading on the films of formed foam. As hydrophobicity of the antifoam increases, the spreading becomes easier and the de-foaming more important.

Acknowledgements

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References

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Recherche sur les propriétés des agents tensioactifs et l’efficacité des produits antimousses dans la fabrication du sucre de betterave (Résumé)

En sucrerie, il se produit – à commencer par le lavoir à betteraves – de la mousse dans tous les secteurs de la fabrication. Dans ce rapport, différents produits antimousses sont comparés au point de vue du mécanisme de leur efficacité et de l’optimisation de leur dosage le plus efficient. L’efficacité relative de six antimousses différents a été déterminée en fonction de leur concentration et de leur température. On a montré que leur efficience augmente avec une concentration croissante jusqu’à une valeur limite. L’influence de...
la température nécessite que le produit antimousse soit ajouté à une température plus élevée que celle du point où se forme la mousse. Pareillement, on a classé les antimopusses en fonction de leur hydrophobicité et leur efficacité à la température normale. On a montré que l’efficacité s’accroît quand l’hydrophobicité augmente. Un antimousse est d’autant plus efficace que son adsorption est faible à l’interface air / liquide. La façon de travailler d’un antimousse s’explique par la répulsion / captation / liaison de la molécule tensioactive du jus par / et à l’antimousse.

La cinétique de l’adsorption a été étudiée à hautes températures pour ces antimousses qui étaient adsorbés rapidement à température normale. On a établi qu’une augmentation de la température favorisait l’adsorption des antimousses à l’interface. Une telle adsorption est d’autant plus forte que l’antimousse est plus efficient à température normale. La diminution de l’énergie d’activation pour l’adsorption des antimousses à la diffusion sur la surface de contact a été proposée comme explication possible pour le comportement des antimousses à la surface de contact.

Estudio de las propiedades de agentes tensioactivos y de la eficacia de agentes antiespumantes en la producción de azúcar de remolacha (Resumen)

Ya en el lavado de la remolacha y luego en la fábrica de azúcar en todas las etapas del proceso se forma espuma. En este trabajo se comparan distintos agentes antiespumantes según sus mecanismos de función y la optimización de la dosis más efectiva. Se determina la eficacia relativa de seis agentes antiespumantes en dependencia de la concentración y de la temperatura. Con mayor concentración también aumenta la eficacia hasta un valor límite. A una temperatura mayor al del punto de turbidez es necesario añadir agentes antiespumantes. Además se caracterizan los agentes antiespumantes según su hidrofobia y su eficacia a una temperatura normal. La eficacia aumenta con una mayor hidrofobia. Cuanto más eficaz es un agente antiespumante, tanto más pequeña es su adsorción en la superficie límite de aire y líquido. Se describe el funcionamiento de los agentes antiespumantes como desplazamiento, captura o adhesión de las moléculas tensioactivas del jugo por o en el agente antiespumante. Se estudió la cinética de adsorción a temperaturas altas y se observó que estas temperaturas apoyan la adsorción en la superficie límite y permiten absorber rápidamente a los agentes antiespumantes. Cuanto más eficaz es un agente antiespumante a temperaturas normales, tanto más fuerte es la adsorción. La reducción de la energía de activación para la adsorción de agentes antiespumantes en la difusión hacia la superficie límite puede ser una explicación para el comportamiento de agentes antiespumantes en superficies límites.

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