THE STUDY OF FOAMING POWER OF SOME FOAM STICKS USED FOR DRAINING WATER FROM GAS WELLS

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Abstract: *Solid foam sticks are designed to increase natural gas production by an average of 30-35%, by reducing the hydrostatic pressure on layer, achieved by the transformation in foam of the deposit water accumulated in well. The obtained foam is easy to exhaust even from the wells with low dynamic pressure at the bottom (depleted deposits). During experimental measurements it was followed the comparative study of foaming power, in dynamic conditions, for some foam sticks dissolved in water or saline solutions of different concentrations. The used surfactants were anionic, cationic or non-ionic. It was followed the influence of foam stick density (over-unit or less than unity), of temperature and of air flow bubbled into the liquid and, in each case, it was determined the foaming speed.*

Keywords: *deliquification, foam, surfactant, surface tension*

INTRODUCTION

Foams have several applications in oil field operations. They are used as a circulation medium for drilling wells, for well cleanouts, and as fracturing fluids. These applications differ slightly from the application of foam as a means of removing liquid from producing gas wells. The former applications involve generating the foam at the surface with controlled mixing and using only water. In gas well liquid removal applications, the liquid-gas-surfactant mixing must be accomplished down hole and often in the presence of both water and liquid hydrocarbons. The principal benefit of foam as a gas well dewatering method is that liquid is held in the bubble film and exposed to more surface area resulting in less gas slippage and a low-density mixture. In addition, foam is a particular type of gas and liquid emulsion. Gas bubbles are separated from each other in foam by a liquid film. Surface-active agents (surfactants) generally are employed to reduce the surface tension of the liquid to enable more gas-liquid dispersion. The liquid film between bubbles has two surfactant layers back to back with liquid contained between them. This method of tying the liquid and gas together can be effective in removing liquid from low volume gas wells. The application of foam to unloading low rate gas wells generally is governed by two operating limitations, which are economics and the success of foam surfactants in reducing bottom hole pressure. Both limits are defined by comparison to other methods of unloading wells [3].

Water soluble sticks contain a combination of surfactants. Natural gas bubbling through the water-column and surfactants produces foam, which can help remove water from watered-up gas wells. These sticks are primarily used to remove water from gas wells and increase gas production. The foaming action decreases the hydrostatic back-pressure which increases gas production that further enhances the foaming action until the well unloads. Also, these sticks can be used to remove fluid from gas-condensate wells and flowing oil wells and to increase the swabbing efficiency and life of swab cups; the extremely slick coating along with the foaming action increases efficiency and life of the swab cups and allows the well to flow easier. The perforations are often cleaned as a result of the surfactants and swabbing action [4].

There are known foaming products based on ionic or nonionic type of water-soluble surfactants in a liquid or a solid form. These compounds are placed in the oil or gas wells either by means of lubricators mounted in the well column (in the case of sparkling liquid introduced into the annular space between the tubing and column), or by gravity through the tubing (in the case of solid foam sticks).

The aim of the experimental determinations was the comparative study of the foaming power of some foam sticks (anionic, cationic or nonionic type), of romanian manufacture. These foam sticks are used for the removal of the water columns in the wells pipes used in the extraction of natural gas and/or oil.

EXPERIMENTAL

Solid foam-forming products were obtained from anionic, cationic or nonionic surfactants and have variable density, less or greater than one. This was done both using substances with adequate densities as well as through the technology for obtaining and casting sticks [5,6]. The homogeneous mass of surfactant is poured, under controlled temperature, in vertical tubes made of low density polyethylene having a length of 1 m and a diameter of 35 mm, followed by cooling for solidification and cutting in the form of sticks of length 100 mm.

In order to measure the surface tension of the surfactant solutions of various concentrations was used the stalagmometer method, using water as the standard liquid [1,2].

The surfactants used have also been characterized by determining the dropping point (Ubbelohde method) [2], respectively by measuring the foaming power under static conditions (Ross-Miles method) [7].

RESULTS AND DISCUSSION

The evolution of surface tension σ depending on the concentration c of surfactant solutions is shown in Fig. 1. Critical micellar concentration CMC corresponds to the minimum of $\sigma = f(c)$ curves. Table 1 presents the equations that give the dependence $\sigma = f(c)$, as well as the values of critical micellar concentration for the three types of surfactants.

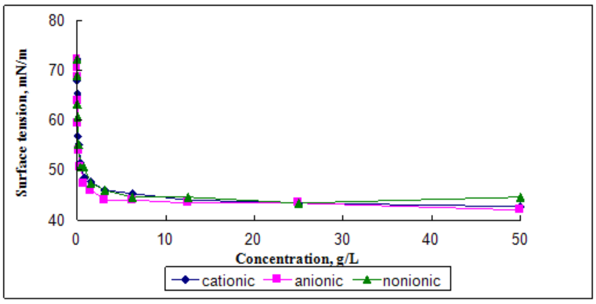

Fig. 1. The dependence $\sigma = f(c)$ for surfactants with density d<1

Table 1. Critical micellar concentrations and the equations $\sigma = f(c)$

Surfactant type	Eq. $\sigma = f(c)$	R^2	CMC, $g \cdot L^{-1}$	$\sigma_{CMC}, mN \cdot m^{-1}$
Cationic	$\sigma = 48.9 \cdot c^{-0.082}$	0.9699	0.266	54.5
Anionic	$\sigma = 50.5 \cdot c^{-0.067}$	0.9428	1.100	49.0
Nonionic	$\sigma = 48.5 \cdot c^{-0.083}$	0.9757	2.200	44.0

The plant used for the experimental determinations of the foaming power of surfactants under dynamic conditions is shown in Fig. 2.

Fig. 2. The experimental plant

It includes a vacuum pump R-300 Boeco that ensures the necessary air flow rate for sparging, flow measured by a rotameter. The water or the saline solution of various concentrations into which is introduced a certain amount of surfactant is placed in a graduated cylinder with a capacity of 1L. Inside the cylinder there is a glass probe provided at the bottom with orifices, connected to the rotameter, that realizes the sparging of air into the solution.

Determinations were performed at four air flow rates measuring, at prescribed intervals, the volume of foam removed from the cylinder. For each air flow rate it was prepared a fresh solution of surfactant: in 1L of water or of saline solution was added a "tablet" of solid surfactant with diameter d= 35mm and height h= 10mm.

In the case of aqueous solutions containing **cationic surfactant**, at 20°C, the variation in time of the volume of liquid removed (V_L) is shown in Fig. 3a (for the product with density d>1), respectively Fig. 3b (for the product with density d<1).

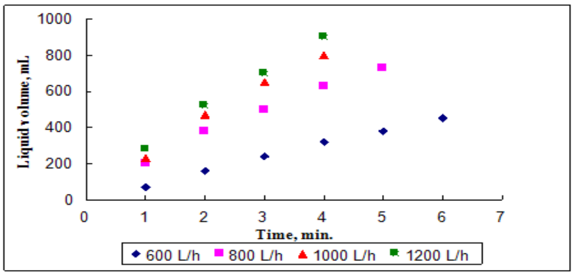

Fig. 3a. The dependence $V_L = f(\tau)$ for cationic surfactant with d>1

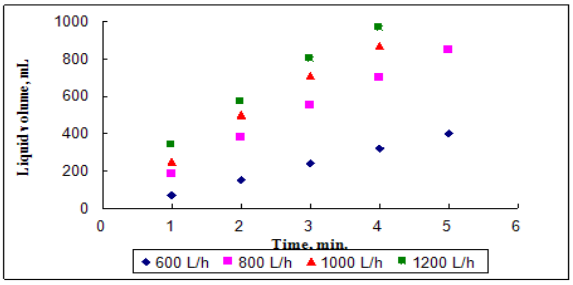

Fig. 3b. The dependence $V_L = f(\tau)$ for cationic surfactant with d<1

It is observed that these dependencies are linear, the obtained equations being presented in Table 2. From the slope of these right lines was calculated the foaming rate w by reporting the volume of the removed liquid on time (τ). It were established the equations that give the dependence $w = f(V_A)$, V_A being the air flow rate. For the situation of cationic surfactant these dependencies are shown in Fig. 4.

Table 2. The equations of $V_L = f(\tau)$ and $w = f(V_A)$ dependencies for cationic surfactant, in water at 20°C

Air flow rate, L/h	Cationic surfactant , d<1		Cationic surfactant, d>1	
	Eq. $V_L = f(\tau)$	R^2	Eq. $V_L = f(\tau)$	R^2
600	$V_L = 87\cdot\tau - 13$	0.9996	$V_L = 75.4\cdot\tau + 6$	0.9957
800	$V_L = 166\cdot\tau + 34$	0.996	$V_L = 131\cdot\tau + 95$	0.9892
1000	$V_L = 207\cdot\tau + 65$	0.9906	$V_L = 189\cdot\tau + 65$	0.9885
1200	$V_L = 210.5\cdot\tau + 142.5$	0.9943	$V_L = 204\cdot\tau + 90$	0.9966
	$w = 0.219\cdot V_A - 29.5$	0.8735	$w = 0.222\cdot V_A - 49.9$	0.9503

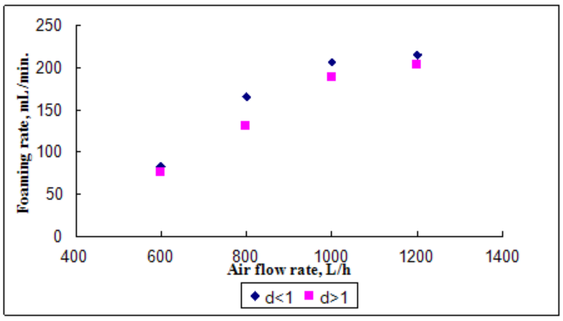

Fig. 4. The foaming rate of cationic surfactant

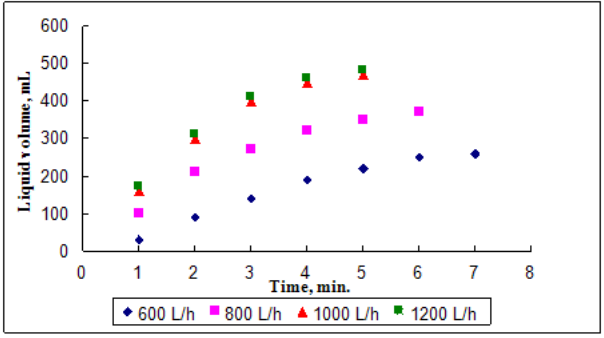

Fig. 5a. The dependence $V_L = f(\tau)$ for nonionic surfactant with d<1

It is noted that at the same air flow rate used for sparging, the foaming rate of the surfactant with density less than unit is slightly higher than that of the surfactant with over-unit density. It should also be noted that in the first stage takes place the increase of the foaming rate with the increase of the air flow rate, after which, at a further increase in air flow rate, the foaming rate decreases its growth.

In the case of aqueous solutions containing **nonionic surfactant**, at 20°C, the variation in time of the volume of liquid removed (V_L) is shown in Fig. 5a (for the product with density d<1), respectively Fig. 5b (for the product with density d>1).

The equations that give the linear dependence between the volume of the removed liquid and the time are presented in Table 3.

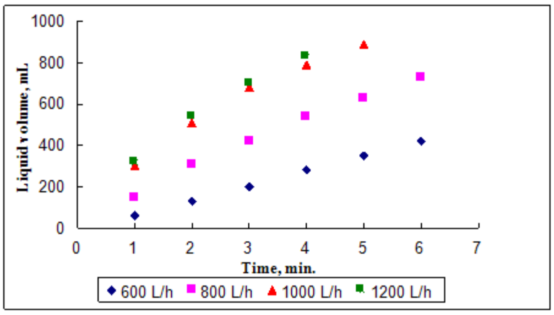

Fig. 5b. The dependence $V_L = f(\tau)$ for nonionic surfactant with d>1

Table 3. The equations of $V_L = f(\tau)$ and $w = f(V_A)$ dependencies for nonionic surfactant, in water at 20°C

Air flow rate, L/h	Nonionic surfactant , d<1		Nonionic surfactant, d>1	
	Eq. $V_L = f(\tau)$	R^2	Eq. $V_L = f(\tau)$	R^2
600	$V_L = 38.9\cdot\tau + 12.9$	0.9581	$V_L = 72.6\cdot\tau - 14$	0.9996
800	$V_L = 52\cdot\tau + 88$	0.9206	$V_L = 114\cdot\tau + 65.3$	0.9911
1000	$V_L = 77\cdot\tau + 125$	0.9077	$V_L = 146\cdot\tau + 196$	0.9737
1200	$V_L = 90\cdot\tau + 135$	0.9077	$V_L = 169\cdot\tau + 175$	0.9857
	$w = 0.089\cdot V_A - 15.8$	0.9823	$w = 0.161\cdot V_A - 19.3$	0.9844

The table also includes the equations that give the dependence of the foaming rate on the air flow rate bubbled in the surfactant solution. For the nonionic surfactant these dependencies are shown in Fig. 6.

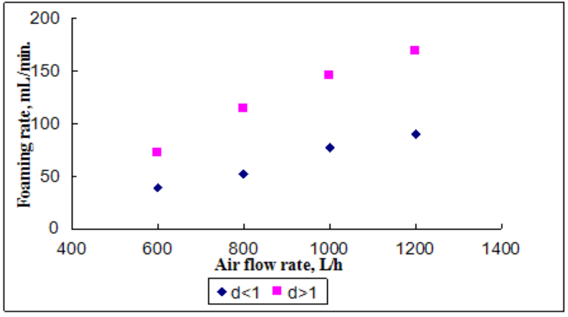

Fig. 6. The foaming rate of nonionic surfactant

From Fig. 6 it can be seen that the solid foamer with over-unit density leads to higher foaming rates and, moreover, the foaming rates increase to both types of surfactant with increasing the air flow rate sparged.

For the nonionic surfactant with over-unit density has also been studied the foaming power in saline solutions of various concentrations, at 20°C. In Table 4 are shown the equations which give the time dependence of the removed liquid, as well as the dependence between the foaming rate and the air flow rate used for sparging.

Table 4. The equations of $V_L = f(\tau)$ and $w = f(V_A)$ dependencies for nonionic surfactant (d>1), at 20°C

Air flow rate, L/h	Sol. NaCl 10%		Sol. NaCl 20%	
	Eq. $V_L = f(\tau)$	R^2	Eq. $V_L = f(\tau)$	R^2
600	$V_L = 74.3 \cdot \tau - 37$	0.9901	$V_L = 82.6 \cdot \tau - 51$	0.9986
800	$V_L = 141 \cdot \tau - 1$	0.9917	$V_L = 123 \cdot \tau - 37$	0.9987
1000	$V_L = 162 \cdot \tau - 10$	0.9951	$V_L = 144.3 \cdot \tau - 80$	0.9994
1200	$V_L = 175 \cdot \tau - 11$	0.9978	$V_L = 165 \cdot \tau - 75$	0.9987
	$w = 0.162 \cdot V_A - 7.3$	0.8683	$w = 0.134 \cdot V_A + 7.9$	0.9693

Fig. 7 shows the influence of the salt concentration from the liquid where the nonionic surfactant is dissolved, on the foaming rate. In this case, when it is dissolved in water, were obtained the lowest values of the foaming rate.

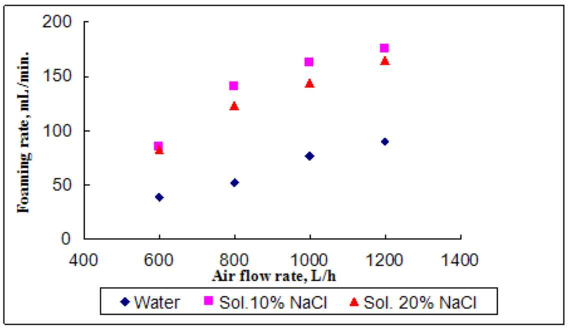

Fig. 7. The foaming rates of nonionic surfactant with d>1, at 20°C

Since the deposit waters, especially found in the exploitation of natural gas, contain electrolytes and have relatively high temperatures, it was studied the foaming power of nonionic surfactant with over-unit density dissolved in aqueous saline solutions (10% NaCl), at three different temperature values.

Fig. 8 shows the influence of temperature on the foaming power of nonionic surfactant dissolved in an aqueous solution of 10% NaCl, at an air flow rate used for sparging of 800L/h.

It is found that the temperature increasing has a favorable effect on the foaming power of the analyzed foamer. This observation is also supported by the evolution of the foaming rates, Fig. 9.

Another series of experimental measurements is the comparative study of the foaming power of a solid surfactant (nonionic, d>1), respectively of a liquid one, in water at 20°C. The foamer concentration was of 5g/L water. In Fig.10a and b are shown the foaming rates of the two surfactants, at two values of the air flow rate.

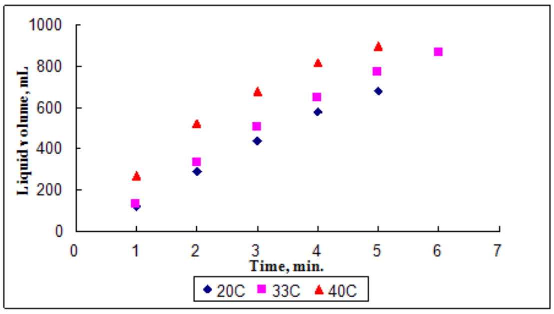

Fig. 8. The dependence $V_L = f(\tau)$ for nonionic surfactant (d>1, sol. 10% NaCl, V_A = 800 L/h)

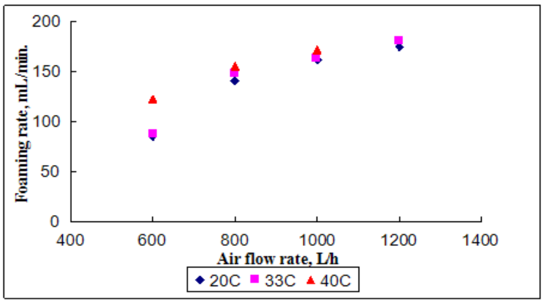

Fig. 9. The foaming rates of nonionic surfactant (d>1, sol. 10% NaCl)

It is noted that when the liquid surfactant was used, at the initial moment, its concentration is maximum (as well as the foaming rate) because of the good solubility in water, after which the concentration sharply decreases and, consequently, the foaming rate (due to the foamer removal together with the formed foam). The solid foamer is slowly dissolved in the liquid, its concentration remains relatively constant and the foaming rate decreases more slowly over time.

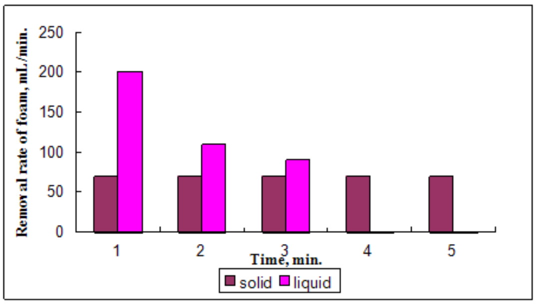

Fig. 10a

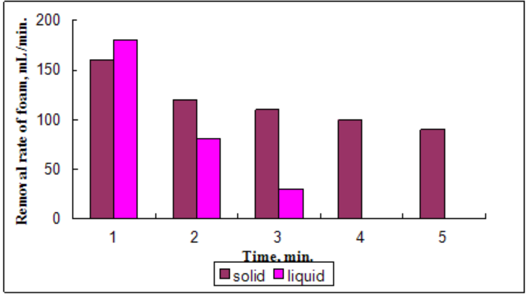

Fig. 10a,b. The foaming rates evolution of nonionic surfactant depending on its state of aggregation: **a)** V_A=600 L/h; **b)** V_A =800 L/h

The study of the foaming power of some solid anionic surfactants was performed for two types of products (anionic_1 and anionic_2) differing in weight ratio of the constituents. In addition, anionic_2 contains crusts and corrosion inhibitors.

In the case of aqueous solutions containing **anionic surfactant**, with density d<1, at 20°C, the variation in time of the volume of liquid removed (V_L) is shown in Fig. 11a and Fig. 11b.

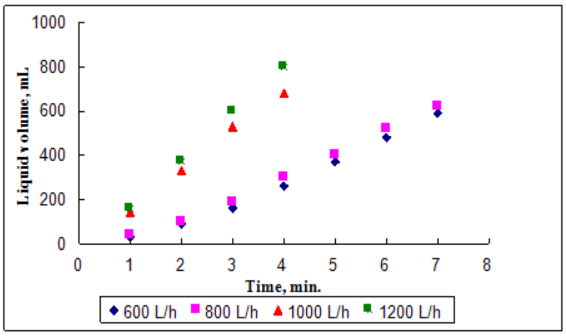

Fig. 11a. The dependence $V_L = f(\tau)$ for anionic_1

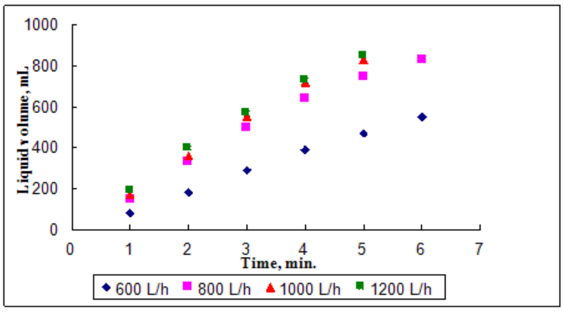

Fig. 11b. The dependence $V_L = f(\tau)$ for anionic_2

For the anionic_2 surfactant with density d<1, at 20°C, the variation in time of the volume of liquid removed (V_L) is shown in Fig. 12a, respectively, in Fig. 12b.

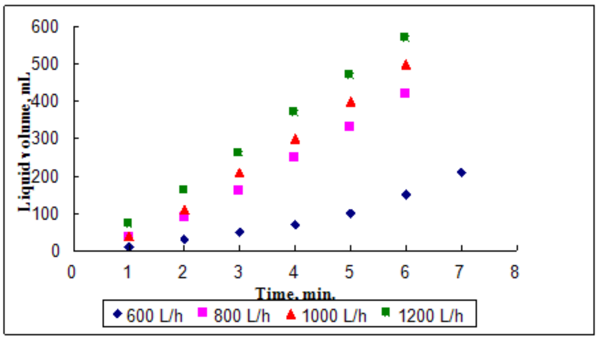

Fig. 12a. The dependence $V_L = f(\tau)$ for anionic_2 surfactant, sol. 10% NaCl

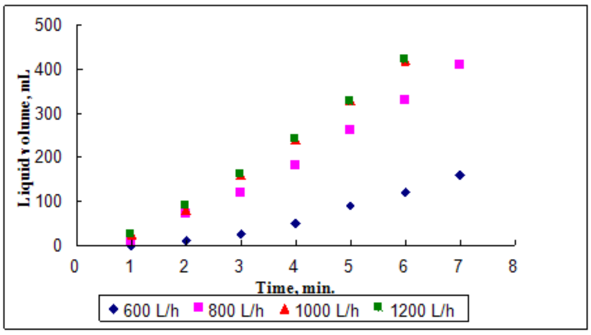

Fig. 12b. The dependence $V_L = f(\tau)$ for anionic_2 surfactant, sol. 20% NaCl

In Fig. 13 are comparatively shown the foaming rates of anionic_2 surfactant.

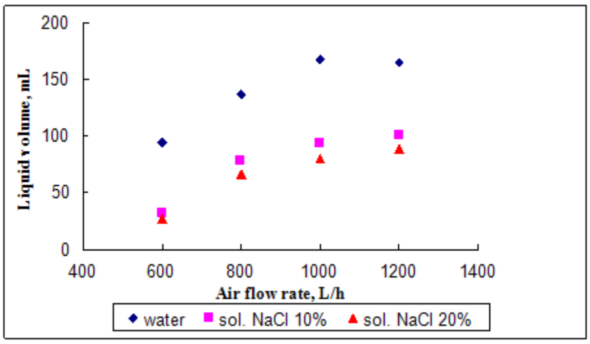

Fig. 13. The foaming rates of anionic_2 surfactant (20°C)

It is noted that in the case of anionic_2 surfactant, the foaming rate decreases with increasing the salinity of the solution in which it is dissolved.

For the analyzed situations the equations that give the dependence between the volume of the removed liquid and the time are presented in Tables 5a and 5b. The tables also include the equations that give the dependence of the foaming rate on the air flow rate used for sparging in the surfactant solution.

Table 5a. The equations of $V_L = f(\tau)$ and $w = f(V_A)$ dependencies for anionic surfactants, in water at 20°C

Air flow rate, L/h	Anionic_1 surfactant, d<1		Anionic_2 surfactant, d<1	
	Eq. $V_L = f(\tau)$	R^2	Eq. $V_L = f(\tau)$	R^2
600	$V_L = 95.4 \cdot \tau - 99$	0.9886	$V_L = 95 \cdot \tau - 5.3$	0.9866
800	$V_L = 129.6 \cdot \tau - 89$	0.9936	$V_L = 137 \cdot \tau + 53.3$	0.9864
1000	$V_L = 172 \cdot \tau - 35$	0.9965	$V_L = 168 \cdot \tau + 22$	0.988
1200	$V_L = 215 \cdot \tau - 55$	0.9994	$V_L = 165 \cdot \tau + 53$	0.9673
	$w = 0.2 \cdot V_A - 27.5$	0.9972	$w = 0.121 \cdot V_A + 32.5$	0.8447

Table 5b. The equations of $V_L = f(\tau)$ and $w = f(V_A)$ dependencies for anionic_2 surfactant, at 20°C

Air flow rate, L/h	Sol. NaCl 10%		Sol. NaCl 20%	
	Eq. $V_L = f(\tau)$	R^2	Eq. $V_L = f(\tau)$	R^2
600	$V_L = 32 \cdot \tau - 39$	0.9865	$V_L = 27.3 \cdot \tau - 44.3$	0.9816
800	$V_L = 78 \cdot \tau - 59.3$	0.9906	$V_L = 66.4 \cdot \tau - 69$	0.9844
1000	$V_L = 93 \cdot \tau - 66$	0.9925	$V_L = 80 \cdot \tau - 71.3$	0.9877
1200	$V_L = 101 \cdot \tau - 37.3$	0.9984	$V_L = 89 \cdot \tau - 66$	0.9623
	$w = 0.111 \cdot V_A - 24.3$	0.8629	$w = 0.099 \cdot V_A - 23.6$	0.8872

CONCLUSIONS

The aim of this paper was to highlight the value of using of the analyzed products, namely the removal of water columns from the gas wells tubing through the foaming effect.

Each of the analyzed products were eliminated the water column by foaming with a lower or a higher rate.

For the specific conditions of each gas wells is necessary a particular type of foam stick:
- if the gas source is located at the bottom of the pipe it can be used foamers with over-unit density;
- if the gas source is placed randomly in different areas of the pipe are used foamers with density less than unit;
- if the water to be removed has a high electrolyte load, nonionic foamers can not be used because their solubility in water is inversely proportional to the electrolyte concentration. In these cases will be used ionic foamers;
- if the water drives clays which swell in contact with it making difficult the movement, will be used cationic foamers.

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