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Evaluation of drops dimensions and rheological properties in production of multiple emulsion in a vessel

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The structure and size of droplets of the inner phase of a multiple emulsion and rheological properties of the produced multiple emulsion are presented in this paper. The multiple emulsion was produced in a stirred vessel equipped with four baffles. In the study, two different stirrers: turbine impeller and Rushton turbine impeller were used. The liquids used in the produced multiple emulsion were: distilled water and refined sunflower oil. 8 g and 16 g lecithin from soya beans were used as an emulsifier. The preparation time was respectively 15 min. and 45 min. The structure of the obtained emulsions is presented in the form of photos taken with the diagnostic inverted microscope. The results size of droplets were presented in the form of graphics as a distribution of drops. The rheological properties of the multiple emulsion were presented graphically and it was described using the rheological model.

Keywords: multiple emulsion, microscopic analysis, rheological properties.

INTRODUCTION

The multiple emulsion can be a promising alternative to application in the pharmaceutical or medicine industries[1–3], cosmetics[4, 5] and food[6–9]. The inner phase is important in O/W/O or W/O/W multiple emulsions because it can contain drugs, pharmaceutical substances used in medicine, cosmetics or nutritional substances in the food industry.

The structure and size of the drops of the inner phase of a multiple emulsion may be affected by the method of its preparation or the emulsifier used, as well as the time and method of storing the emulsion. In the available literature, the assessments of quality, stability and rheological properties are carried out on emulsions produced by the two-step method[9–14] and emulsions produced by the single-step method[15–20].

Technological development influences the search for new technical solutions to produce multiple emulsions. One such solution may be the use of a tank with a stirrer. Li et al.[16] used the IL – ionic liquid (3-methyl-1-octylimidazolium hexafluorophosphate), water and TX-100 (poly(ethylene glycol)-*tert*-octylphenyl) according to different water volume fractions (0.10–0.90) for preparation of emulsions in a capped glass vessel with magnetic bar inside. Interestingly, the multiple emulsions (W/IL/W) were formed for the water volume fractions in the range of 0.68–0.75. The single-step emulsification process was used by Zhang and Li[17], Li and Zhang[18], too. They prepared emulsions while homogenizing through high shear mixer. Major-Godlewska[19, 20] used a tank with four flat baffled and Smith turbine to prepare the emulsion.

The size of the dispersed phase droplets is one of the parameters characterizing emulsions. To describe the size of the multiple emulsion droplets is used their diameter d presented as the median diameter d_m[19–21], mean diameter $d_a = \Sigma x_i d_i / \Sigma x_i$[19, 20, 22, 23], volume-surface (Sauter) mean diameter $d_{32} = \Sigma x_i d_i^3 / \Sigma x_i d_i^2$ [19, 20, 24–26] or volume-weighted (De-Brouker) mean diameter $d_{43} = \Sigma x_i d_i^4 / \Sigma x_i d_i^3$ [25–27]. Droplet sizes in multiple emulsions are usually presented as diameters distribution[2, 21,24,26–29]. Droplet size in emulsions is important for maintaining their stability. Stability properties were conducted by observing multiple emulsion structures after 1, 2, 3, 4 weeks[17], 1, 5, 10, 15, 20, 25, 30 days[18] or 3 and 30 days[19]. In the last case, the sample was stirred or shaken before observing the structure after 3 and 30 days[19].

The structure, droplet size and stability of the emulsion may be influenced by the emulsion preparation method and the emulsifiers used. Various emulsifiers are used to maintain emulsion stability, including polyglycerol polyricinoleate (PGPR)[9, 22], Tween 20[2, 30], Tween 80[2], Tritonu X-100[2], xanthan gum[18, 31], pectin[30], lecithin[19, 20, 31]. It is especially worth paying attention to the use of natural emulsifiers in the production of multiple emulsions in the food, cosmetic, or pharmaceutical industries. One such natural emulsifier is lecithin. Lecithin, due to its emollient properties of the epidermis through which the proper active ingredient can penetrate, can be used in the production of multiple emulsions used in the pharmaceutical or cosmetic industry. Lecithin belongs to the group of natural, amphoteric emulsifiers[32, 33]. Not only stability but also deformation and disintegration of droplets are the subject of research[34]. The breakup behavior can be described and predicted by the viscosity ratio using the viscosity of the inner and outer emulsion, respectively[35].

Rheological properties including viscosity[2, 18, 23, 31, 36] storage modulus[2, 18, 31, 36] or loss modulus[2, 18, 31, 36] are other important parameters analyzed when characterizing emulsions. The rheological properties of liquids change with the change in emulsion structure and droplet size. The analysis of the rheological properties of the W/Si/W emulsion, formed in the process of one-stage emulsification, was presented by Li and Zhang[18]. According to Li and Zhang[18] the rheological properties of the W/Si/W multiple emulsion were consistent yet different from the simple emulsion, with a yield stress and steady viscosity at the low shear rate. Tian[31] analyzed the effect of lecithin concentration on the viscosity value of multiple W/O/W emulsions. Han[3], researching W/O/W double gel emulsions, found that the rheological behavior analysis showed that their gel emulsions showed a clear elastic behavior.

The research aimed to define the structure of the emulsion produced, including the size of the internal phase droplets and to study the rheological properties of the multiple emulsion produced using soya lecithin as an emulsifier. The tests were carried out for two different types of stirrers: turbine impeller or Rushton turbine impeller and two different stirring time using two different amounts of lecithin to produce an emulsion.

MATERIALS AND METHODS

The emulsions were produced in a stirred vessel. The geometrical parameters of the vessel were: the vessel of inner diameter $D = 0.1$ m, the height of the liquid $H = 0.5D$ and four ($J = 4$) standard planar baffles $B = 0.1D$. Turbine impeller (T90) with pitch of impeller blade $\beta = 90^o$ and number of impeller blades $Z = 6$ was used in the measurement. Rushton turbine (RT) impeller with $Z = 6$ blades was used as a second impeller to produce the emulsion. In both cases, the diameter of the impeller was $d_t = 0.33D$.

Materials

The liquids used in the tests were: distilled water as water phase, and refined sunflower oil produced for Jeronimo Martines Polska S.A. as oil phase. Sudan III (producer: Eurochem BGD Sp. z o. o.) was used to color the oil. Lecithin from soya beans is produced for Vemica as an emulsifier.

Preparation of emulsion

Emulsions were produced following a similar procedure to the described work Major-Godlewska[19, 20]. 8 g or 16 g of soy lecithin was solved in distilled water and stirred with magnetic stirrer until mixture homogeneity was obtained. A mixture of distilled water with soy lecithin was poured into the vessel with four standard baffles and impeller. Sunflower oil which was coloured with Sudan III was poured into the mixture. The part of individual phase contained 30 vol.% of water phase and 70 vol.% of oil phase. The emulsion was produced by stirring two phases, water and oil phase, in the vessel with turbine (T90) impeller. The rotation frequency n of the impeller was 500 rpm. It corresponds to tip velocity $w_t = \pi d_t n = 0.86$ m/s. Samples of the produced emulsion were taken after 15 and 45 minutes of stirring. The formation emulsion procedure was repeated for two amounts of lecithin and the Rushton turbine (RT).

The structure and droplet size of the produced emulsion were performed using the diagnostic inverted microscope OPTA-TECH MW 100, with software and digital camera OPTA-TECH 5MP. Before taking photos using the microscope, the sample of the produced emulsion taken for testing was placed on the plate and covered with the glass slide. The rheological measurements of multiple emulsion samples were carried out on a rheoviscometer of type RT 10 by firm Haake with the system of two co-axial cylinders (DG41). The rheological properties of the produced emulsion were measured at 23 °C and shear rate was $\gamma < 50$ 1/s.

RESULTS AND DISCUSSION

Based on 8 measurement series differing in the type of impeller, the amount of lecithin and the stirring time, after which the sample was taken for testing, the total number of drops of the inner oil phase was taken to the analysis, amounting to 4890. From each series, the population of inner oil phase drops in the number from 604 to 624 was taken to the analysis.

Determination of the structure and type of emulsion

Based on a series of photos taken, the structure and size of the drops of the inner oil phase were determined. Fig. 1 and Fig. 2 are illustrative images, presented only to show the structure and type of emulsion.

The structure of the emulsion obtained in the vessel with turbine impeller with pitch of impeller blade $\beta = 90^o$ and the amount of lecithin equal to 8 g or 16 g used as an emulsifier for both times (15 and 45 min.)

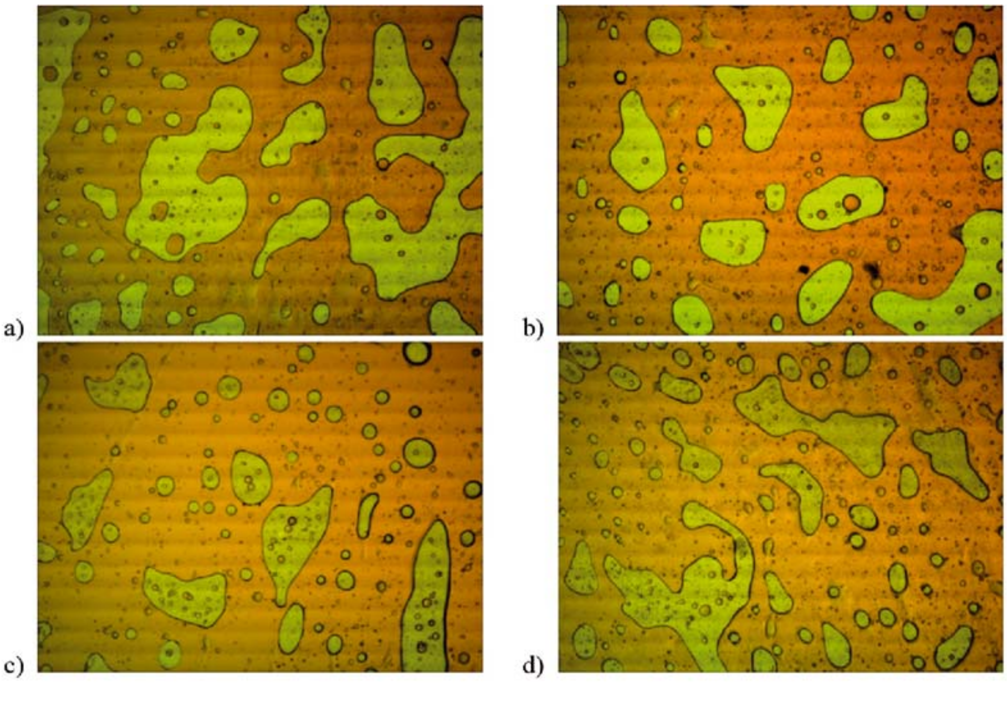
a) b) c) d)

Figure 1. Images of drops of multiple emulsion O/W/O produced in a vessel with the turbine (T90) impeller for: a) lecithin 8 g, time 15 min.; b) lecithin 8 g, time 45 min.; c) lecithin 16 g, time 15 min.; d) lecithin 16 g, time 45 min.; (enlargement 4x)

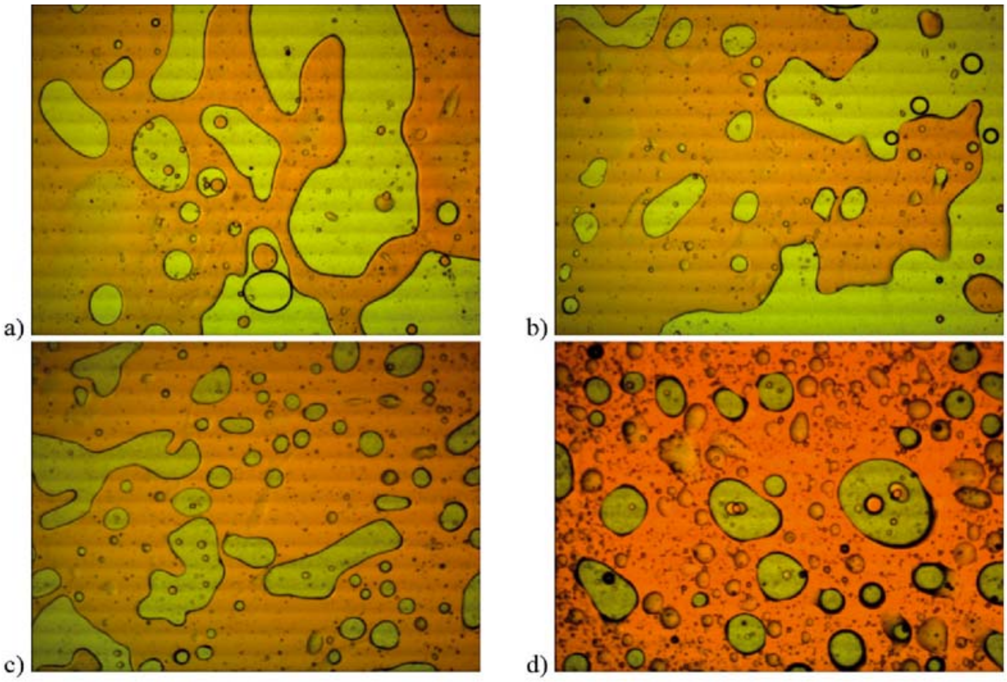

Figure 2. Images of drops of multiple emulsion O/W/O produced in a vessel with the Rushton turbine (RT) for: a) lecithin 8 g, time 15 min.; b) lecithin 8 g, time 45 min.; c) lecithin 16 g, time 15 min.; d) lecithin 16 g, time 45 min.; (enlargement 4x)

is shown in Fig. 1. In all four cases, it was observed that an unstable multiple emulsion was formed. The multiple emulsion produced is described as oil in water in oil (O/W/O). The shape of the water phase in the obtained emulsions is irregular. They were deformed by the applied microscope slide.

Similar emulsion structures (Fig. 2) can be observed when the Rushton turbine was used to produce emulsion. In this case, the unstable multiple O/W/O emulsion with different shapes of the water phase is also formed, the shape of which was influenced by the applied microscope glass.

Droplet size distribution

Based on the obtained droplet diameters of the inner oil phase of multiple emulsion (O/W/O), their distributions in the form of histograms were determined. Example distributions (in the form of histograms) of the droplet diameter of the inner oil phase of the emulsion produced in the vessel with the turbine impeller (T90) for 15 min. and 45 min. shown in Fig. 3 for the emulsion produced with 8 g of soy lecithin as the emulsifier and in Fig. 4 when 16 g of soy lecithin was used. Analyzing the data presented in both Fig. 3 and Fig. 4, it was found that the size of the droplet diameters is affected by both the amount of lecithin used as well as the time of stirring, after which the sample was taken for testing.

In the case when 8 g of soy lecithin was used to produce the emulsion, the biggest collection of inner oil phase drop diameters was observed (Fig. 3a), amounting to about 34% of the entire analyzed population of drops for the range from 1.75 μm to 3.5 μm and time 15 min. A similar trend was observed when the sample was taken after 45 min. stirring. At that time, the biggest set of diameters was obtained, amounting to about 41%, for the range from 1.71 μm to 3.42 μm (Fig. 3b). In the analyzed populations, about 94% drops, where the diameter is $d \leq 10.5$ μm (Fig. 3a) and about 96% are drops with a diameter $d \leq 10.26$ μm (Fig. 3b).

A different droplet distribution of the inner oil phase of the O/W/O emulsion is observed when the amount of lecithin used is 16 g (Fig. 4a–4b). For the emulsion produced using turbine (T90) impeller, 16 g soy lecithin as an emulsifier and both times (15 and 45 min.) the most numerous (about 50%) is the first range, where the diameter is $d \leq 2.05$ μm for the time stirring of 15 min. and about 44% for $d \leq 2.19$ μm and time 45 min. The number of drops in the second range from 2.05 μm to 4.1 μm for 15 min. and from 2.19 μm to 4.38 μm for 45 min. is similar and amounts to 203 and 201, respectively.

Diameters values analysis

Based on the obtained droplet diameters of the internal oil phase, the mean arithmetic diameter d_a, median d_m and the mean Sauter diameter d_{32} were calculated. Diameter values d_a, d_m and d_{32} of the internal oil phase were determined from the diameters of drops obtained from samples taken after 15 and 45 min. during the

Table 1. The mean arithmetic diameter d_a, median d_m and the mean Sauter diameter d_{32} from the population of drops obtained for the emulsion stirred with turbine impeller (T90) or Rushton turbine (RT) for times of 15 min. and 45 min. and for lecithin 8 g and 16 g

Impeller	Lecithin	15 min.				45 min.			
		Number	d_a µm	d_m µm	d_{32} µm	Number	d_a µm	d_m µm	d_{32} µm
T90	8 g	617	4.03	2.46	19.58	607	3.33	1.98	19.42
	16 g	624	3.92	2.08	31.59	616	4.66	2.46	26.46
RT	8 g	604	4.13	2.08	62.40	608	2.92	1.96	13.24
	16 g	608	3.13	1.98	15.72	606	5.28	3.09	35.98

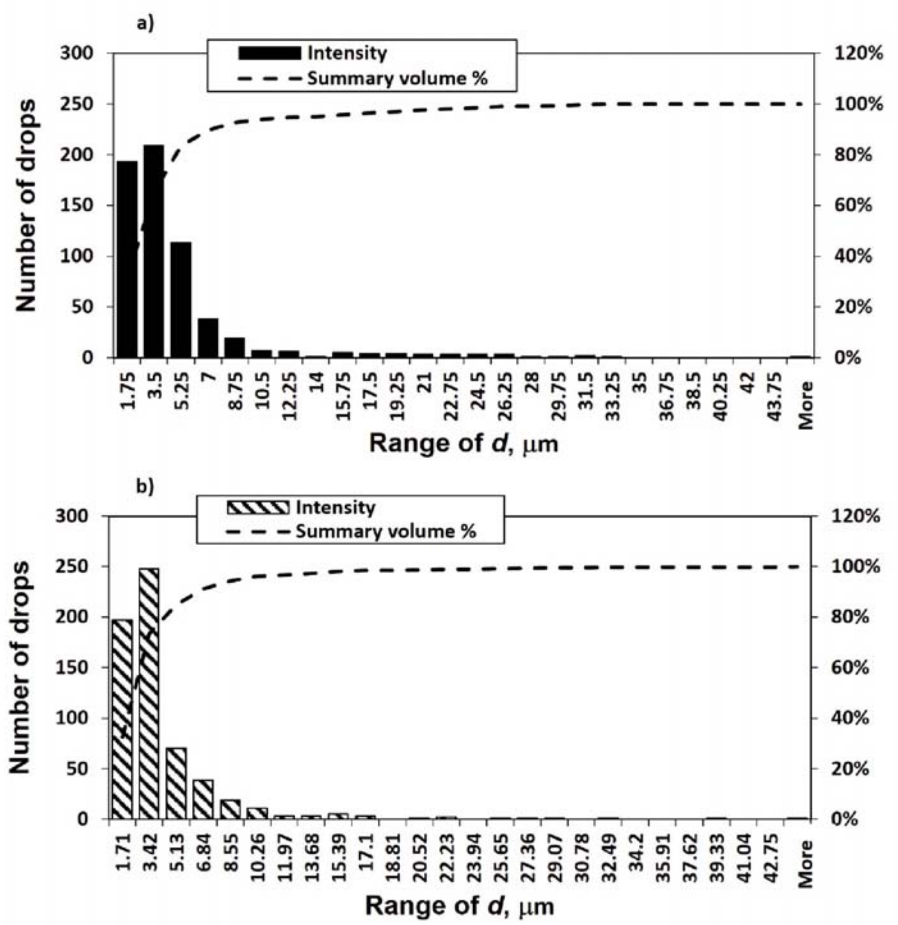

Figure 3. Distribution of inner oil-phase drops of O/W/O emulsion produced in a vessel with the turbine (T90) impeller for 8 g lecithin and time: a) 15 min.; b) 45 min

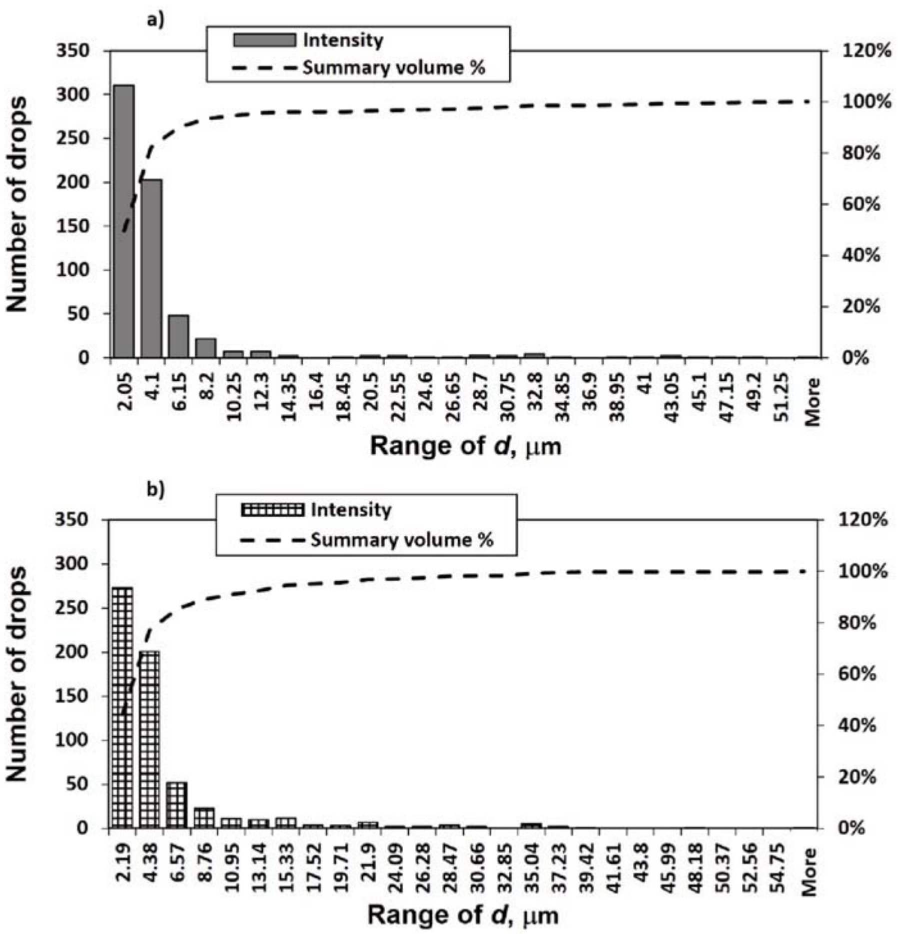

Figure 4. Distribution of inner oil-phase drops of O/W/O emulsion produced in a vessel with the turbine (T90) impeller for 16 g lecithin and time: a) 15 min.; b) 45 min

production of the emulsion with the use of a turbine impeller (T90) and a Rushton turbine (RT), as well as for two different amounts of lecithin used as an emulsifier, 8 g and 16 g, are presented in Table 1.

Analyzing the data presented in Table 1, it was found that lower values of the arithmetic mean d_a = 3.92 μm (T90) and d_a = 3.13 μm (RT) were obtained for the emulsion for which 16 g of lecithin was used, and the time after which the sample was taken for testing was 15 min. compared to the values, d_a = 4.03 μm (T90) and d_a = 4.13 μm (RT), obtained for the emulsion for which 8 g of lecithin was used for the same times. When samples were taken after 45 min. lower values of the arithmetic mean diameter d_a = 3.33 μm (T90) and d_a = 2.92 μm (RT) were obtained when 8 g of lecithin was used to prepare the emulsion. When 16 g of lecithin was used to prepare the emulsion the values of the arithmetic mean diameter were d_a = 4.66 μm (T90) and d_a = 5.28 μm (RT) for time 45 min. Analyzing the median values obtained for both stirrers used in the tests (T90, RT) and two different amounts of lecithin used (8 g, 16 g) it was found that for the stirring time of 15 min. the highest value of the median d_m = 2.46 μm was obtained for the case in which the turbine impeller (T90) was used to produce the emulsion. The same median value was obtained with the emulsion prepared for 45 min. using the turbine impeller (T90) and 16 g of lecithin as an emulsifier. The lowest value of the median d_m = 1.96 μm was obtained for the case in which the Rushton turbine impeller (RT), 8 g of lecithin and time of 45 min. were used to produce the emulsion. Not much higher median values d_m = 1.98 μm were obtained for two cases, i.e. for the emulsion produced using a Rushton turbine impeller, 16 g of lecithin and stirring time 15 min. and when the turbine impeller (T90) was used to produce the emulsion, 8 g lecithin and a longer stirring time of 45 min. The highest value of the median d_m = 3.09 μm was obtained for the case of emulsion production for 45 min. using the Rushton turbine (RT) where 16 g lecithin was used.

Analyzing the obtained Sauter diameters, it was found that the highest Sauter diameter value d_{32} = 62.4 μm was obtained for the case in which the emulsion produced was stirred for 15 min. with a Rushton turbine impeller (RT), where 8 g of lecithin was used as an emulsifier. This value is approximately 3 times higher than the value obtained with a turbine impeller (T90) using 8 g of lecithin and a time of 15 min. The lowest value of the Sauter diameter d_{32} = 13.24 μm was obtained for the case in which the produced emulsion was stirred for 45 min. Rushton turbine impeller (RT), where lecithin in the amount of 8 g was used as the emulsifier.

In the case when the turbine impeller (T90) was used to prepare the emulsion, with 8 g of lecithin used as an emulsifier, lower values of the mean arithmetic diameter d_a = 3.33 μm, median d_m = 1.98 μm and Sauter diameter d_{32} = 19.42 μm were obtained, when the emulsion production time was longer and amounted to 45 min. Although in the case of the Sauter diameter d_{32}, the difference in the obtained values is small. For a turbine impeller (T90), 8 g lecithin, 15 min. the Sauter diameter value is d_{32} = 19.58 μm. When 16 g of lecithin are used in the produced emulsion, lower values of the mean arithmetic diameter d_a = 3.92 μm, medians d_m = 2.08 μm were obtained for the stirring time of 15 min. compared to the values obtained for 45 min. d_a = 4.66 μm, medians d_m = 2.46 μm. Only the Sauter diameter d_{32} is smaller for longer stirring times: d_{32} = 26.46 μm (45 min.), d_{32} = 31.59 μm (15 min.).

Analyzing the same values of diameters d_a, d_m, d_{32} obtained when the Rushton turbine impeller was used to prepare the emulsion, it was found that when the emulsion production time was extended from 15 min. up to 45 minutes reduced the diameter values when using 8 g of lecithin. For time 45 min. the values of the mean arithmetic diameter d_a = 2.92 μm, the median d_m = 1.96 μm and the Sauter diameter d_{32} = 13.24 μm were obtained, where for 15 min. these values were d_a = 4.13 μm, d_m = 2.08 μm and d_{32} = 62.4 μm using 8 g of lecithin. Increasing the amount of emulsifier used from 8 g to 16 g of lecithin and increasing the stirring time from 15 min. up to 45 minutes increases the values of the obtained diameters from d_a = 3.13 μm, d_m = 1.98 μm and d_{32} = 15.72 μm for 15 min. to d_a = 5.28 μm, d_m = 3.09 μm and d_{32} = 35.98 μm for 45 min.

The influence of the shape of the blades on the droplet diameters of the internal oil phase obtained during the formation of the O/W/O emulsion can be observed by comparing the data obtained for the Rushton turbine impeller (RT) - flat blades and the Smith turbine impeller (CD 6) – curved blades[19, 20].

Analyzing the values of droplet diameter presented in the form of the median d_m, it can be concluded that the curvature of the blades has a greater impact on the obtained d_m values than the addition of a disc to the turbine impeller. For the case in which the emulsion was produced using 8 g of lecithin and both times: 15 and 45 min. median values range from 1.96 μm (for RT and 45 min.) to 2.46 μm (for T90 and 15 min.). The use of an impeller with curved blades, as in the case of the Smith turbine impeller (CD 6), results in higher d_m values. According to Major-Godlewska[19] when preparing an emulsion using 8 g of lecithin and the time of 15 min. the d_m value is 3.88 μm and 2.96 μm for 45 min. These are more than 50% higher values compared to the d_m values obtained when the Rushton turbine impeller (RT) (d_m = 2.08 μm) or a turbine impeller (T90) (d_m = 2.46 μm) was used for 15 min. and 8 g of lecithin and about 50% higher when the emulsion preparation time is longer 45 min. (RT d_m = 1.96 μm, T90 d_m = 1.98 μm).

A similar tendency is observed when 16 g of soy lecithin was used to prepare the emulsion and 15 min. In this case, the differences between the d_m values obtained when a Rushton turbine impeller was used to produce the emulsion (d_m = 1.98 μm) and the d_m values obtained from the droplet diameters obtained when producing the emulsion with a Smith turbine impeller (d_m = 2.46 μm)[20], are smaller. However, when the emulsion is prepared using 16 g of lecithin and a time of 45 min. greater differences in the d_m value are visible when an impeller without a disk, such as a T90 turbine impeller (d_m = 2.46 μm), is used to produce the emulsion than one of the disk – turbine impellers (RT d_m = 3.09 μm, CD 6 d_m = 3.02 μm)[20].

Comparison of the diameter droplets

Additionally, the collected set of drops was compared, assuming $d \leq 20$ μm. The number of drops belonging to such a set constitutes over 95% of the analysed population of inner oil phase drops.

Comparing the data presented in Fig. 5a obtained during the preparation of the emulsion with the use of a turbine impeller (T90), over 300 drops of the internal oil phase were observed for diameters in the range of $d \leq 2$ μm for 15 min. and 16 g of lecithin and with an increased time of 45 min. with a smaller amount of lecithin – 8 g. A similar tendency, for the same range d ≤ 2 μm, is maintained (Fig. 5b) when Rushton's turbine impeller (RT) was used to prepare the emulsion.

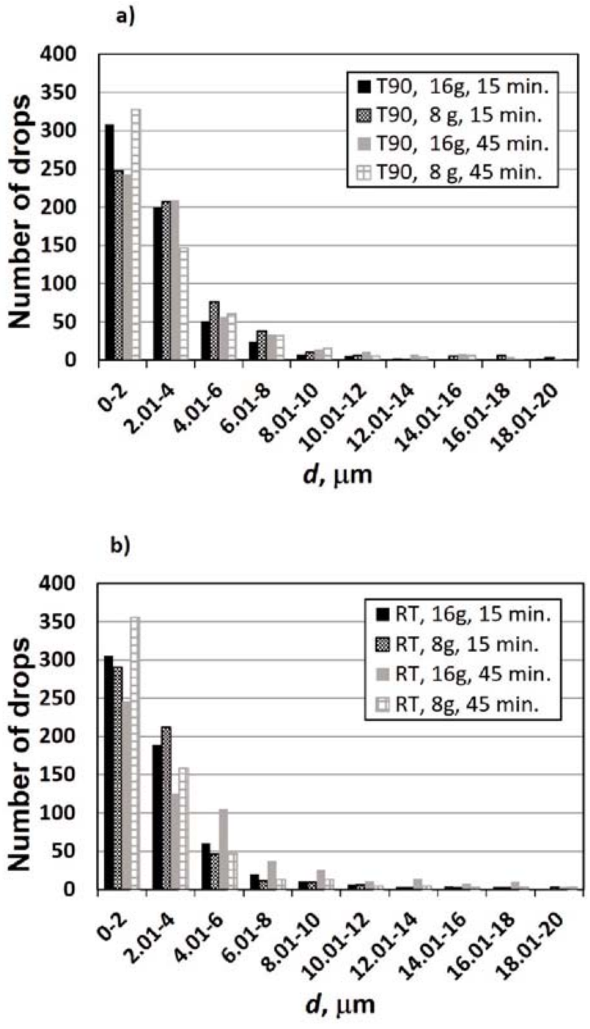

Figure 5. Number of drops = f(d) for two different time 15 min. and 45 min., amount of lecithin 8 g and 16 g and type impeller: a) turbine (T90), b) Rushton turbine (RT)

Comparing the data presented in Fig. 6a obtained from the emulsion produced with the use of a turbine impeller (T90) with the data obtained from the emulsion produced with the use of a Rushton turbine impeller (RT), which its additionally equipped with a disc, it was found that a greater number of droplets with values of $d \leq 4$ μm were obtained when the stirrer used to produce the emulsion was a Rushton turbine impeller (RT).

A smaller impact of the type of impellers used while maintaining the same production time is visible when a larger amount of lecithin was used (16 g). It can be observed that the number of drops of the internal oil phase for diameters up to $d \leq 2$ μm is comparable both when the turbine impeller (T90) and the Rushton turbine impeller (RT) are used (Fig. 6b). The situation is different in the case of the range from 2.01 μm to 4 μm, wherewith the same amount of lecithin and the same time, a larger number of drops in this range was obtained for the turbine impeller (T90). In the case when a Rushton turbine impeller was used to prepare the emulsion, it was found that increasing the amount of added lecithin and extending the time during which the emerging emulsion was stirred from 15 min. up to 45 minutes resulted in a reduction in the number of drops in the range $d \leq 4$ μm and an increase when the analyzed diameter range is 4.01 μm $< d <$ 20 μm. Such a distribution of the number of drops illustrates the distribution of drops with less differentiated diameters.

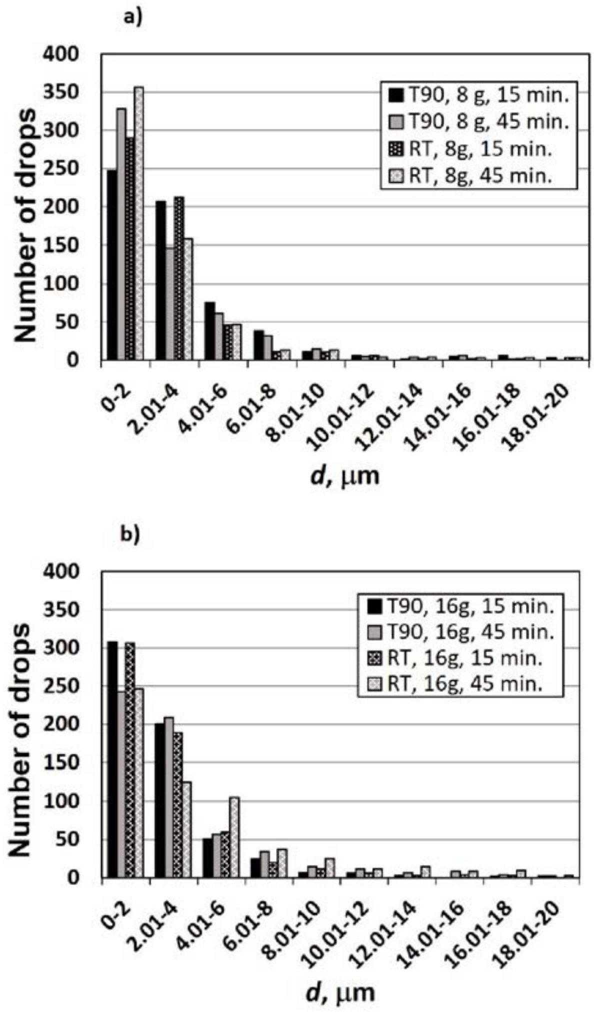

Figure 6. Number of drops = f(d) for the two different type impeller: turbine (T90) and Rushton turbine (RT), time 15 min. and 45 min and a) 8 g lecithin, b) 16 g lecithin

Rheological properties

The rheological properties of the emulsion produced were also analyzed and they were presented as $\tau = f(\gamma)$ in Fig. 7. The amount of lecithin used to prepare the emulsion affects the rheological properties. Higher shear stress values for the same shear rate were obtained when a larger amount of lecithin was used to prepare the emulsion.

Analyzing the data presented in Fig. 7a in the form of the relationship τ = f(γ), it was found that for the emulsion produced using a turbine impeller (T90) and 16 g of soy lecithin, lower values of shear stress for the same shear rate were obtained for the emulsion produced in longer time (45 minutes). No such differences were observed in the shear stress values at a constant shear rate when analyzing the values obtained for the emulsion prepared using a turbine impeller and a smaller (8 g) amount of lecithin. Analyzing the shear stress data at constant shear rates for the emulsion prepared using a Rushton turbine impeller where 8 g of soy lecithin was used to prepare the emulsion, it was found that the τ values are comparable for $\gamma < 15$ 1/s (Fig. 7b). At higher values of shear rate $\gamma > 15$ 1/s, higher values of τ were obtained for the emulsion that was prepared for a longer time (45 min.).

The values of shear stress τ obtained from measurement for shear rates in the range $1 < \gamma$, 1/s < 50 were described using the Herschel-Bulkley model. This model was chosen to describe the rheological properties to present subtle differences that appear in the exponent of the equation.

The values of constant and exponent of Herschel-Bulkley model obtained based on experimental data are presented in Table 2 for the emulsion which was produced using the turbine impeller (T90) and in Table 3 for the emulsion which was produced using the Rushton turbine (RT). The mean relative error was below 5% for equations (Table 2 and Table 3) describing the rheological properties of the produced emulsion.

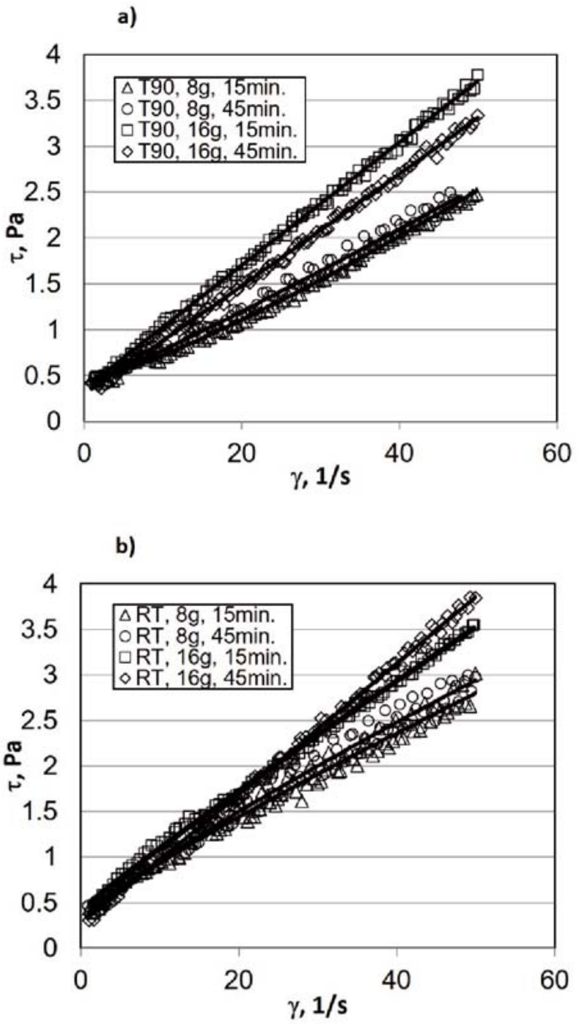

Figure 7. Relation τ = f(γ) for the produced emulsion for two different time 15 min. and 45 min., amount of lecithin 8 g and 16 g and type impeller: a) turbine (T90), b) Rushton turbine (RT)

Table 2. Equations describing the rheological properties of the produced emulsion which was produced using the turbine impeller (T90)

No.	Soy lecithin	Time	Equations
1	8 g	15 min.	$\tau = 0.436 + (0.0165 \cdot \gamma^{1.237})$
2	8 g	45 min.	$\tau = 0.403 + (0.0303 \cdot \gamma^{1.091})$
3	16 g	15 min.	$\tau = 0.356 + (0.0677 \cdot \gamma^{0.998})$
4	16 g	45 min.	$\tau = 0.307 + (0.0539 \cdot \gamma^{1.028})$

Table 3. Equations describing the rheological properties of the produced emulsion which was produced using the Rushton turbine impeller (RT)

No.	Soy lecithin	Time	Equations
1	8 g	15 min.	$\tau = 0.356 + (0.0758 \cdot \gamma^{0.888})$
2	8 g	45 min.	$\tau = 0.301 + (0.09 \cdot \gamma^{0.864})$
3	16 g	15 min.	$\tau = 0.413 + (0.0784 \cdot \gamma^{0.941})$
4	16 g	45 min.	$\tau = 0.284 + (0.0656 \cdot \gamma^{1.022})$

CONCLUSIONS

Based on the conducted research, it was found that the use of a turbine impeller (T90) or a Rushton turbine impeller (RT) and 8 g or 16 g of soy lecithin for 15 min. and 45 min., for the same number of individual phases (30 vol.% water phase, 70 vol.% oil phase), allows the creation of an unstable multiple O/W/O emulsion. The structures of the multiple emulsions obtained during the tests are presented in the form of photos of drops of the internal oil phase dispersed in the water phase located inside the oil phase in Fig. 1 and Fig. 2.

The final effect consists of the entire emulsion production process, so it is important what drop sizes and rheological properties of the emulsion are obtained in the production process. The size of the obtained drops of the internal oil phase was analyzed for 8 measurement series in which the type of impeller, the amount of soy lecithin used and the time during which the emulsion was produced changed. The obtained droplet diameters of the internal oil phase were presented in the form of histograms and the form of arithmetic diameter d_a, median d_m and Sauter diameter d_{32}. The highest value of the Sauter diameter was obtained from the diameters obtained for the emulsion created during stirring with a Rushton (RT) turbine impeller, in which 8 g of soy lecithin was used to prepare and the production time was 15 min. This value was influenced by the presence of single drops with a diameter $d > 80$ μm. The smallest value of the Sauter diameter $d_{32} = 13.24$ μm was obtained for the emulsion produced by the same impeller (RT) with the same amount of lecithin (8g), but for a longer time of 45 min. For the same emulsion production conditions, the lowest median value $d_m = 1.96$ μm and the mean arithmetic diameter $d_a = 2.92$ μm were also obtained. The highest value of the median $d_m = 3.09$ μm and the diameter $d_a = 5.28$ μm was obtained for the emulsion produced using a Rushton turbine impeller after 45 min. preparation using 16 g of lecithin.

The obtained rheological data are presented graphically as relation τ = f(γ) and they were described with the appropriate Herschel-Bulkley model. The values of the constant and exponent of Herschel-Bulkley model are presented in Table 2 for the emulsion which was produced using the turbine impeller (T90) and in Table 3 for the emulsion which was produced using the Rushton turbine (RT).

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