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Original Research

Statistical Analysis of the Grey Water Solid Phase with the Coanda Effect Separator

Zbigniew Dąbek*

The Research Station for Experimental Phytotechnologies in Mlodziejowice near Kraków, Poland

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Abstract

The phenomenon of the solid phase separation with the Coanda Effect separator was discovered by Henry Coanda in 1914 and a mathematical formula was presented by Albert Metral in 1934. The phenomenon, which was observed as attraction of the fluid jet to a nearby surface, was used by the Swedish in 1990 for the construction of a separator, named the Aquatron 90. Laboratory analyses of the solid phase separation with the Aquatron 90 were conducted at the Agricultural University in Kraków 2006-07. The research was performed using a half-technical scale on the fully-measured station equipped with an Aquatron 90 separator. The efficiency of separation was obtained and measured as 96.24% at the fall of the input pipe (*i*) equal 2%. The results were then statistically analyzed using JVT Statistica 6.0 software. The one-component analysis results were presented through score estimation and multi-componential methods. The conclusion was subsequently developed from these findings.

Keywords: Coanda Effect separator, solid phase, curved surfaces, household sewage

Introduction

Many scientific publications describing the Coanda Effect point to Albert Metral (1902-62), professor of L'Ecole Politechnique de Paris, as the pioneer of the technique who published the mathematical interpretation of the phenomenon of the attraction of a fluid jet to nearby surfaces. An interpretation of this phenomenon, which was observed by the engineer Henry Coanda (1886-1972) during a jet flight in 1914 (in the connection between a shaft engine and compressor), led Metral to patent this effect in France and the U.S. in 1914. The Coanda Effect may be easily replicated by holding a teaspoon under a thin stream of water running from the tap. The running stream is attracted to and curves toward the curved surface of the teaspoon. However, in the case of an extremely convex surface, e.g. a sphere, the stream will not stick to the surface tightly but bend and fall away from it [1, 2]. The separation of the solid phase of household sewage began to be closely examined in the beginning of the 1990s. At first, the subject was dealt with by only a few scientific centers in Sweden. Advanced research on separation was carried out much later, in Upssala by B. Vinnerås and H. Jönsson in the years 2001-02 [8, 9], in Stockholm by U. Winblad in 2004 [10], and in Kraków at the Agricultural University by Z. Dąbek in 2006 [3]. The research was aimed at describing statistically the significant differences that could determine the phase separation of the fluid-solid mixture in a separator utilizing the Coanda effect.

Materials and Methods

The laboratory research upon the subject matter carried out in 2006-07 was the first pioneering work ever performed in Poland. It was conducted on a semi-technical scale, on the full-measures separator model at the Hydro-Technical Laboratory of the Agricultural University in

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*e-mail: phytoremedia.station@gmail.com

Table 1. The results obtained from the laboratory tests in the series at the fall (*i*) ranging from 1.0% to 2.0%.

Series (*i*) [%]	Flushing water volume V [dm^3]	Substratum [gram]		Fall of the input pipe (*i*) [%]	Efficiency of the separation η [%]	The separate volume Sw [dm^3]	Average optimum values	
		Peas	Paper				Speed of sewage v [m·s^{-1}]	Flow intensity Q [dm^3·s^{-1}]
1.0	50.0	90	7	1.0	95.5	2.22	1.19	0 .92
1.5		90	7	1.5	95.3	2.30	1.27	0.96
2.0		90	7	2.0	96.3	1.87	1.31	1.12

Kraków. The experimental station was fixed and equipped with an Aquatron 90 separator at the top (Fig. 1).

The separator was a two-part device made entirely of polystyrene. The upper part, in the shape of an eliptisoidal torus, was equipped with a radial input and floating pipe. The bottom part joined the upper in the centre, where the curved surface was turned into the pipe. At this place there was a shutter with a palisade of thin, elastic wires. Their presence was intended to separate the solid phase from a whirling stream of sewage in the torus just before leaving the separator [6, 7].

For the implementation of the afore-mentioned method, a self-made and unique fecal-phase substitute filler was used and made up of a mixture of peas and toilet tissue. The equivalent of the standard amount of the fecal matter for adult *homo sapiens* is 90 g. The substitute for the tests was taken in the following amounts: 90 g peas and 7 g of printed toilet tissue. The adequate parameters such as current and speed of the stream were obtained by changing only one parameter; the fall of the input pipe (*i*). The falls were set at three values for *i* equal subsequently to 1.0%, 1.5%, and 2.0%. The parameter of the volume of the flushing fluid was set as 50 dm^3 for one cycle.

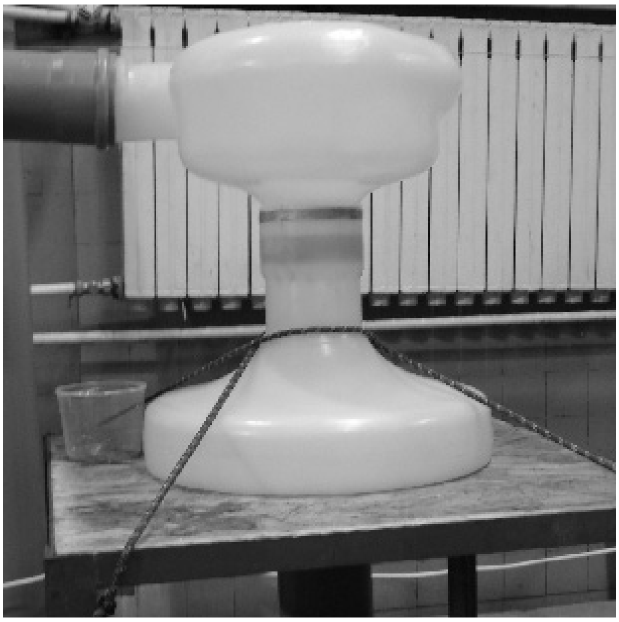


Fig. 1. The solid phase separator, Aquatron 90 model, at the experimental station.

Results and Discussion

A realization of the research program was conducted with many approaches to the subject and various parameters setting precisely the dynamic parameters of the sludge. The statistical results obtained in the laboratory trials were collected and presented in Table 1.

Then, the results of the laboratory tests were analyzed using the Shapiro-Wilk method. Numerical calculations of the series (*i*) equal 1.0% showed that the mean random $\overline{x}$ of the separate reached the value $\overline{x}$ equal to 2.24 dm^3, while in the results obtained in the laboratory tests for the mean general μ the value μ equals 2.22 dm^3. The data was set within the limits established by the estimated interval values of the quartiles: lower equalling 2.14 dm^3 and upper equalling 2.33 dm^3. The deviation of the statistical significant σ in the laboratory tests resulted in the value σ equal to 0.11 dm^3, seen in Table 2.

In fact, the comparison between the values demonstrated the similarity.

The research conducted with the torques method in the analysis of variance allowed the precise assessment of the value of the obtained results and their parallel comparison between the pairs in the series. Fig. 2 shows the differences obtained in the compared laboratory and numerical results and their observation suggested that they were correct.

In the laboratory (Table 1) and numerical tests (Table 2) the mean average μ reached the values that differed but not significantly with little load set by the estimator. The estimation interval was included within the limits determined by the quartiles: lower for $\overline{x}$ equal 2.24 dm^3 and upper for $\overline{x}$ equal 2.35 dm^3 and the low standard deviation σ equal 0.198 dm^3 confirmed the correctness of the results obtained and shown in Tables 1 and 2.

For the purpose of the laboratory tests, the rule was applied and, in accordance with this, the result in the series which exceeded the limit of water stopped by the separator *SepW* ~2 dm^3 was disqualified because of the ballast of liquid diluting the separate. The results confirmed the assumptions about similarity and correctness, set and aimed at in the hypothesis of the laboratory research, conducted on the large amount of the population results. The analysis of the results proved that a chosen factor (*i*) influenced the separation process performed with the Coanda Effect Separator. Moreover, this factor had an influence on the volume of the liquid stopped in the separate *SepW*. The data presented in

Table 2. The estimation parameters of the detained separate *SepW* in the series 1.0, 1.5, and 2.0% [dm^3].

Type of parameter of Symbol		Estimation in series (*i*) [%]			Lower quartile in series (*i*) [%]			Upper quartile in series (*i*) [%]		
		1.0	1.5	2	1.0	1.5	2.0	1.0	1.5	2.0
Mean random	$\bar{x}$	2.24	2.29	1.87	2.14	2.24	1.86	2.33	2.33	1.88
Standard deviation	σ	0.33	0.19	0.04	0.27	0.16	0.03	0.41	0.24	0.05
Mean general	μ	2.22	2.30	1.87	*	*	*	*	*	*

Table 2 and the fall *i* equal 2.0 % allowed us to draw the following conclusion: applying the fall of the input pipe *i* equal 2.0 % was the most influential for the quantities of the separate stopped *SepW*. The results obtained with the use of statistical analysis also confirmed the assumptions of the hypothesis. The graphic interpretation of the analysis of variance in the series: 1.0% 1.5%, and 2.0% of the liquid stopped in the separate *SepW* was shown in Fig. 2. The obtained results were presented in Table 3 and showed that at the fall *i* equal 2.0 % for the liquid separate *SepW* it had the most influence on the amount of the detained separate [4-6].

Table 3. The estimation parameters in the series from 1.0% to 2.0% [dm^3] with ANOVA analysis.

Series (*i*) [%]	Number of tests *N*	Standard deviation *μ* [dm^3]	Mean general σ [dm^3]	Lower quartile	Upper quartile
1.0	50	2.24	0.03	2.17	2.30
1.5	50	2.29	0.03	2.23	2.36
2.0	50	1.87	0.03	1.80	1.93

In the analysis of variance, the statistical method of parameters dependent on many active factors was applied with the division into the following models:

- single-factor models (point estimation), t-Student analysis
- multi-factor models – the pair analysis in the Tukey-Kramer method with the following subdivision into: A fixed-effects model ascribed to the series of values; for *i* equalling subsequently: 1.0% 1.5%, and 2.0%. A mixed-model in which some categories were determined by the t-Student test while the remainder underwent a random choice with the Tukey-Kramer method.

The estimator, if unloaded, sets its own load on the parameters, and each parameter separately leads to the loss of dependences among them. Hence, it was assumed that the distribution had occurred as a result of a secret choice of a parameter that underwent estimation *α*. Such a preparation of the data for the analysis was presented in Table 3.

Also, the pairs with the falls *i* were compared with the t-Student test method and the results illustrated in Fig. 3.

The treatment with the use of the Tukey-Kramer HSD method resulted in the values shown in Table 4.

The estimator levels from the Tukey-Kramer HSD method were compared, but not in pairs, and the results were of a various degree-likelihood agreement. It meant

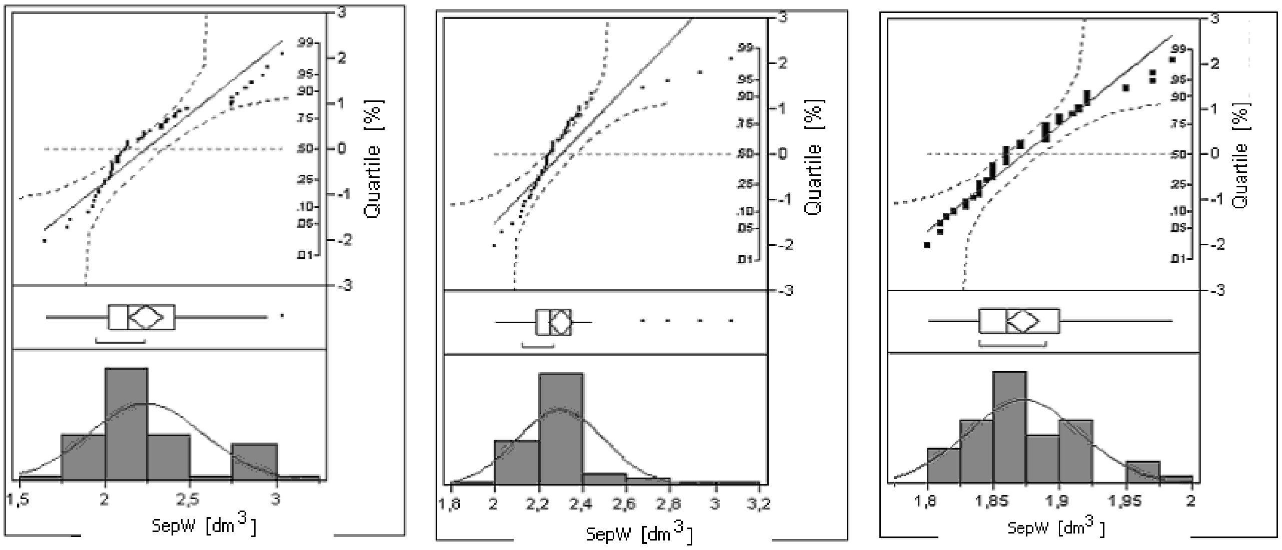
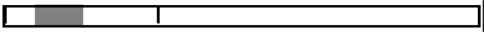

a) for *i* = 1.0% **b)** for *i* = 1.5% **c)** for *i* = 2.0%

Fig. 2. Graphs showing moments and estimation of the separation process in the series (*i*) [%]of the liquid stopped in the separate *SepW* [dm^3].

Table 4. The parallel comparison tests with the Turkey-Kramer HSD method and the falls of the input pipe (*i*) [%].

Series of *SepW* in pairs (*i*) [%]		Estimator load	Lower quartile	Upper quartile	Results of the comparison seen as differences
1.5	2.0	0.42	0.33	0.51	
1.0	2.0	0.36	0.28	0.45	
1.5	1.0	0.05	0.03	0.14	

that with this method, the estimator set its own load on the results, unrelated to the laboratory results obtained, with the estimation interval determined by the lower and upper quartiles. The greatest level of agreement with the results was observed for the series at the falls (*i*) equal subsequently: 1.0 and 1.5%, but it differed from the series at the fall (*i*) equal to 2.0% whose estimated values of parameters were assessed as more advantageous in the tests and presented in Table 3. Both the responses at the falls *i,* which were compared in parallel, in pairs and the results obtained from the laboratory tests, allowed conclusions to be drawn regarding the commercial use of the findings.

The statistical analysis results obtained owing to the parallel comparisons made in pairs are shown in Table 4. It was noticed that the flow through the input pipe at the fall (*i*) equal 2% had differed significantly from all the results obtained where those falls were smaller so that only the value of fall *i,* which equals 2%, seemed the most advantageous result.

Conclusions

The statistical analysis of the results measured in the laboratory allowed the following conclusions to be drawn:

1. The statistical analysis performed on the populations in the series, 1.0% and 2.0%, allowed for the definition of the correctness of the laboratory test results in a wider interval context.
2. The results of the interval estimation of laboratory tests of the liquid separate *SepW* confirmed the series *i* equal 2.0% (Fig. 2c) to be the most advantageous with the minimum value in the tests μ equal 1.87 dm^3, and the standard deviation error for the whole test σ equal 0.03 dm^3 (Table 3). The minimum quantity of the detained liquid separate *SepW* confirmed the assessment made in the earlier laboratory research about the efficiency of the separation of the stream flow through the input pipe at the fall (*i*) equalling 2%, and thus it allowed an assumption about the use of the results for building small, economical, and odor-free homestead sewage treatment plants that would be equipped with a well settling tank with high suspension reduction effect.
3. The series (*i*) equalling 2.0 % (Fig. 2c) reached the highest efficiency of the separation in the tests η_v equal 96.2%, which implied the possibility of their future practical uses.
4. The parallel comparison, in pairs, with the Tukey-Kramer HSD method, as seen in Table 4 and in the series at the falls (*i*) ranging from 1.0% to 2.0%, resolved the differences among the series also as to have been more advantageous at (*i*) equalling 2.0% for the smallest amount of the liquid stopped in the separate *SepW*. Also, it fulfilled the assumptions set in the hypothesis and confirmed the aims of this research.
5. The results of the statistical analysis aimed at the efficiency of the solid phase separation with the Coanda Effect Separator allowed for preparation of the whole documentation for the patent notification P-387896 titled "The well settling tank practical for the homestead sewage treatment plant."

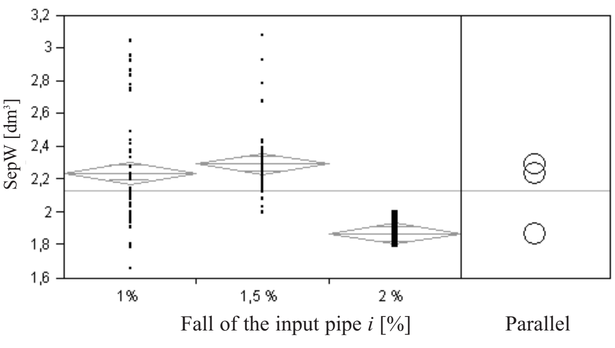


Fig. 3. The analysis of the liquid separate *SepW* [dm^3] in the parallel system of the falls (*i*) [%] with the t-Student method.

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