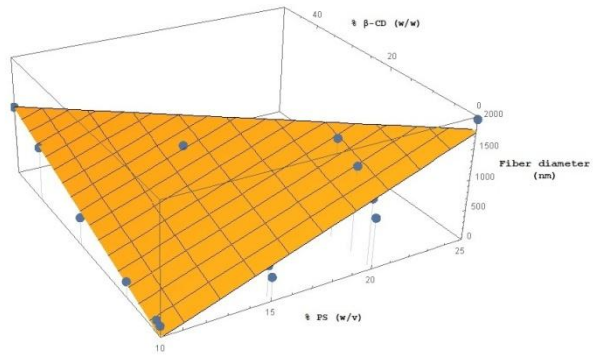

Fig. 3. The fiber diameter and β-CD/PS concentration relationship; linear model.

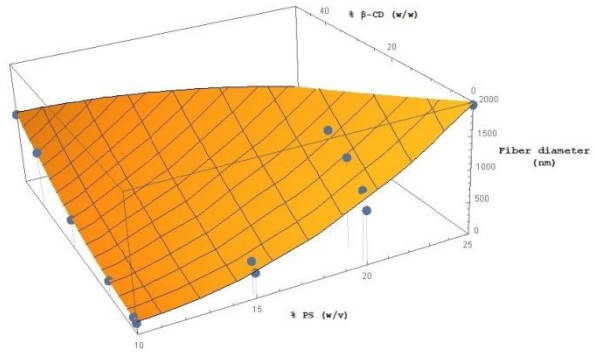

Fig. 4. The fiber diameter and β-CD/PS concentration relationship; quadratic model.

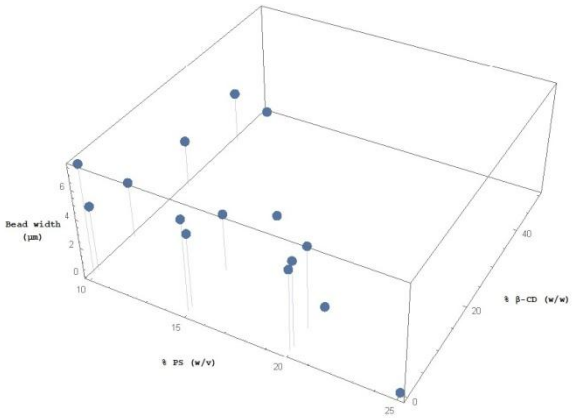

Fig. 5. The beads width experimental data results.

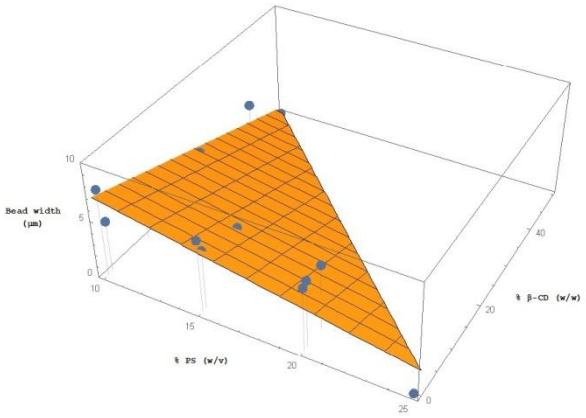

Fig. 6. The beads width and β-CD/PS concentration relationship; linear model.

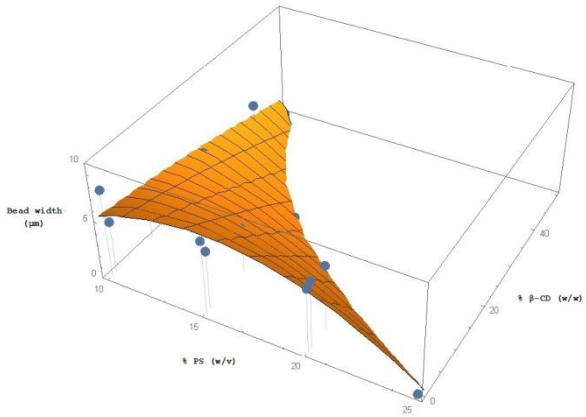

Fig. 7. The beads width and β-CD/PS concentration relationship; quadratic model.

4 Conclusions

The experimental way of the electrospinning process design is often cost- and time-consuming. The uniform fibers production needs advanced knowledge based on the process specified experience. It is worth to say, that each experiment is related with electrospinning solution preparation, nanofibers formation and the fibers characterization by using sophisticated devices, (e.g. scanning electron microscope (SEM) or transmission electron microscope (TEM)). To overcome these difficulties and facilitate tedious optimization procedure model-based design approach was presented in this work. Thus, 3-dimensional polynomial models were discussed. To describe a chosen experimental relations meet in the nanofibers production, two polynomial models (linear and quadratic) were proposed. The experimental data were used to the model parameters optimization. As a result, the reasonable set of parameters was indicated, as well as the dependencies between fiber diameter/beads width and β-CD/PS concentration were considered. Although the quadratic model resulted with better fitting features, the linear model also can be used to improve an experimental

procedure design. The proposed methodology points out desired concentrations of the electrospinning solution components and will also make it possible to obtain bead-free nonwovens with certain fiber diameter.

As it was indicated, some specified nanofibers features can be described using multidimensional polynomial models, that can be applied in the real-life experimental procedures. The proposed models allow us to gather fully characterized specification of desired fibers production. Moreover, due to a small amount of required parameters they are very convenient, whereas definitely bigger set of information is required (e.g. jet radius, jet curvature, surface tension coefficient, etc.) when solving models based on the Newton's Second Law of motion [1].

The presented in this work 3-dimensional polynomial models may stand an effective approach to the practical tool development for the electrospinning process design associated with the environmental field of study, where cyclodextrin functionalized nanofibers production is extremely required (e.g. filtration, separation and purification processes) [2]. What is more presented models may be useful not only in the production of the functionalized nanofibers, but also in the other electrospinning processes leading to the structures of diverse morphology and characteristics.

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References

1. S. Ramakrishna et al., *An Introduction to Electrospinning and Nanofibers (*WSPC, Singapore, 2005)
2. T. Uyar et al., Nanotechnology **20** (2009)
3. A. Celebioglu et al., J. Incl. Phenom.Macro **90**, 135–141 (2018)
4. Kenry et al., Prog. Polym. Sci. **70**, 1–17 (2017)
5. S. Rafiei et.al., Cell. Chem. Technol. **47**, 323–338, (2013)
6. L. Weng et al., Curr. Pharm. Design. **21** (2015)
7. A. Celebioglu et al., Chemosphere **144**, 736–744 (2016)
8. E. M. Martin Del Valle, Process. Biochem. **39**, 1033–1046 (2004)
9. E. Gatica et al., J. Photoch. Photobio. A. **348**, 295–304 (2017)
10. L.T. Biegler, *Nonlinear Programming: Concepts, Algorithms, and Applications to Chemical Processes* (SIAM, Philadelphia, 2010)
11. J.T. Betts, *Practical Methods for Optimal Control and Estimation Using Nonlinear Programming* (SIAM, Philadelphia, 2010)
12. L.T. Biegler, et al., *Control and Optimization with Differential-Algebraic Constraints* (SIAM, Philadelphia, 2012)
13. J. Nocedal et al., *Numerical Optimization* (Springer, Heidelberg, 2006)
14. A.E. Senador Jr. et al., Mat. Res. Soc. Symp. Proc. **661**, KK5.9.1–KK5.9.6 (2001)