Fig. 13 indicates that an increased in the optimal value of D_p will result in a decreased in the total cost (c_{tot}). Since the operating cost is proportional to $\frac{1}{D^2}$ in the equation, a decreased value of the operating cost tends to be more dominant in affecting the value of total cost.

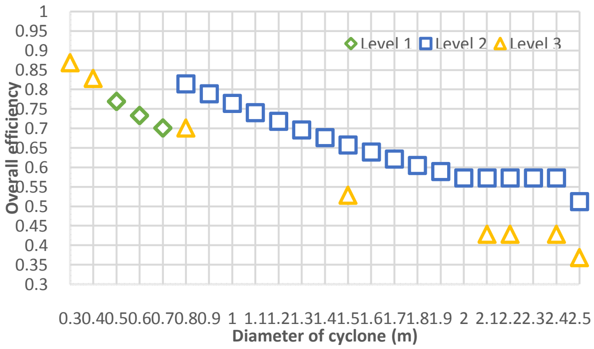

Fig. 12 Optimal solution of overall efficiency of the arrangement

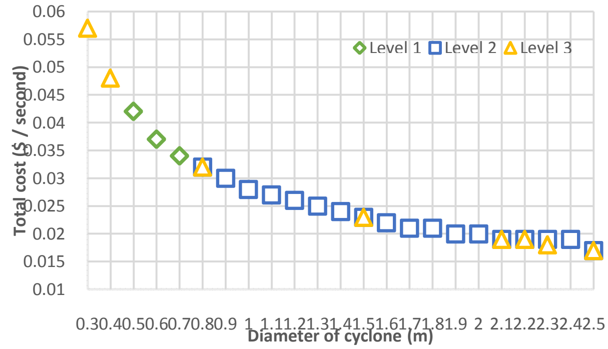

Fig. 13 Optimal solution of the total cost

Another result shows that, at D_p = 2.1 m, there are two different types of cyclone arrangements (level 2 and level 3) will have the similar optimum number of parallel lines (N_p = 13) and the same total cost (Fig. 13). However, the overall efficiency of 2D2D+2D2D is higher than 1D3D+2D2D (Fig. 12). In addition, the pressure drop of all cyclone arrangements can also be accepted, since the values were obtained in the range of $500 \leq \Delta P \leq 2500$ N/m2.

VI. CONCLUSION

This study proposed the model of mathematical programming for optimization of multiple cyclone arrangement in order to obtain the best cyclone arrangement with the optimal number and dimensions of the cyclone. For this purpose, two mathematical programming techniques are used to optimize different cyclone arrangement i.e., nonlinear programming (NLP) model for 1D3D, 2D2D, and 1D2D cyclones in parallel or in series and mixed integer nonlinear programming (MINLP) model for four combinations of 1D3D and 2D2D cyclones connected in parallel-series. The objective of all these models is to find the optimal number and dimensions of cyclone arrangement with respect to the minimum total cost including the operating cost and the capital cost. The results of NLP optimization show that if the horizontal space is limited on the field, it is advised to use the 1D3D cyclones in parallel because at the same value of minimum total cost and optimal number of cyclone, the 1D3D cyclones will have the smallest dimensions. Meanwhile, for a series arrangement, two 1D2D cyclones in series is more suitable to handle the total dust in the proposed NPK fertilizer plants because it will have the lowest pressure drop with the smallest size of diameter. Moreover, in the MINLP optimization, the cyclone arrangement of 2D2D+2D2D in parallel-series is found as the best arrangement with a higher efficiency and a lower total cost compared to the others.

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REFERENCES

[1] PA Funk, RW Clifford, and SE Hughs. Optimum entry velocity for modified 1D3D cyclones. In ASAE Paper No. 994198. 1999.
[2] CB Shepherd and CE Lapple. Air pollution control: a design approach. Cyclones, second ed., Woveland Press Inc., Illinois, pages 127–139, 1939.
[3] S Simpson and CB Parnell Jr. New low-pressure cyclone design for cotton gins. In Proc. 1995 Beltwide Cotton Production Conferences, pages 680–687, 1995.
[4] Richard E Rosenthal. Gams–a user's guide. 2004.
[5] JM Martinez-Benet and J Casal. Optimization of parallel cyclones. Powder technology, 38(3):217–221, 1984.
[6] P Rosin, E Rammler, and W Intelmann. Principles and limits of cyclone dust removal. Zeit. Ver. Deutscher Ing, 76:433–437, 1932.
[7] R.K. Sinnott. Chemical Engineering Design. Elsevier Butterworth-Heinemann, 2005.
[8] Robin M Smith. Chemical process: design and integration. John Wiley & Sons, 2005.
[9] Roland Clift, John R Grace, and Martin E Weber. Bubbles, drops, and particles. Courier Corporation, 2005.
[10] AC Hoffmann and LE Stein. Gas cyclones and swirl tubes: Principles. Design and Operation, 2nd Edition Springer, 2008.

[11] DP Whitelock and MD Buser. Multiple series cyclones for high particulate matter concentrations. Applied engineering in agriculture, 23(2):131, 2007.

[12] G Ravi, Santosh K Gupta, and MB Ray. Multiobjective optimization of cyclone separators using genetic algorithm. Industrial & engineering chemistry research, 39(11):4272–4286, 2000.

[13] Jaime Benitez. Process engineering and design for air pollution control. Prentice Hall, 1993.

[14] L Wang, CB Parnell, BW Shaw, and RE Lacey. Analysis of cyclone collection efficiency. In Proceedings of 2003 ASAE Annual International Meeting, Las Vegas, Paper, volume 34114, 2003.

[15] Anthony J Buonicore and Wayne T Davis. Air pollution engineering manual. Van Nostrand Reinhold, 1992.

[16] L Wang, CB Parnell, BW Shaw, and RE Lacey. A theoretical approach for predicting number of turns and cyclone pressure drop. Transactions of the ASABE, 49(2):491–503, 2006.

[17] Jolius Gimbun, TG Chuah, Thomas SY Choong, and A Fakhru'l-Razi. A cfd study on the prediction of cyclone collection efficiency. International Journal for Computational Methods in Engineering Science and Mechanics, 6(3):161–168, 2005.

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