Improving Cyclone Efficiency by Recycle and Jet Impingement Streams

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ABSTRACT: *In this paper a new process is presented for improving efficiency of cyclone de-dusting systems. The cyclone is coupled with a specially designed cylindrical chamber which includes a rotating tube inside it with air impinging nuzzles, drilled on the peripheral surface of the tube. The nuzzles help in pushing and throwing the particles to the outer radius distances during downward flow of dust included air stream inside the chamber. In this way dust particles will become concentrated near the surface of the cylindrical chamber which is then collected from a recycling stream, taken from the higher radius zone of the chamber in the lower part and passed through a cyclone for dust removal. The exhaust dusty flow of the cyclone is also recycled to the jet-impingement chamber for further de-dusting. Experiments were conducted on the apparatus by feed stream input to the chamber in such a way that the performances of chamber alone can be investigated with respect to the three variables; feed stream, recycle stream and jet-impingement stream.*

KEY WORDS: *Cyclone, Efficiency Improvement, Dust removal, Jet-Impingement, Recycle Stream.*

INTRODUCTION

Cyclone is a simple, economic and easy to operate equipment for dust removal from gas streams. It works on the basis of centrifugal forces acting on the solid particles. The centrifugal forces are the consequence of tangential input of the dust loaded gas stream to the upper part of the cylindrical section of the cyclone. Since the mechanism of operation in the cyclones is on the basis of centrifugal forces, it is not efficient for fine particles and as a result the separation efficiency decreases with the decrease of particle size. Since the time of discovery of cyclones over a century ago, many researchers have contributed to the large volume of work on improving

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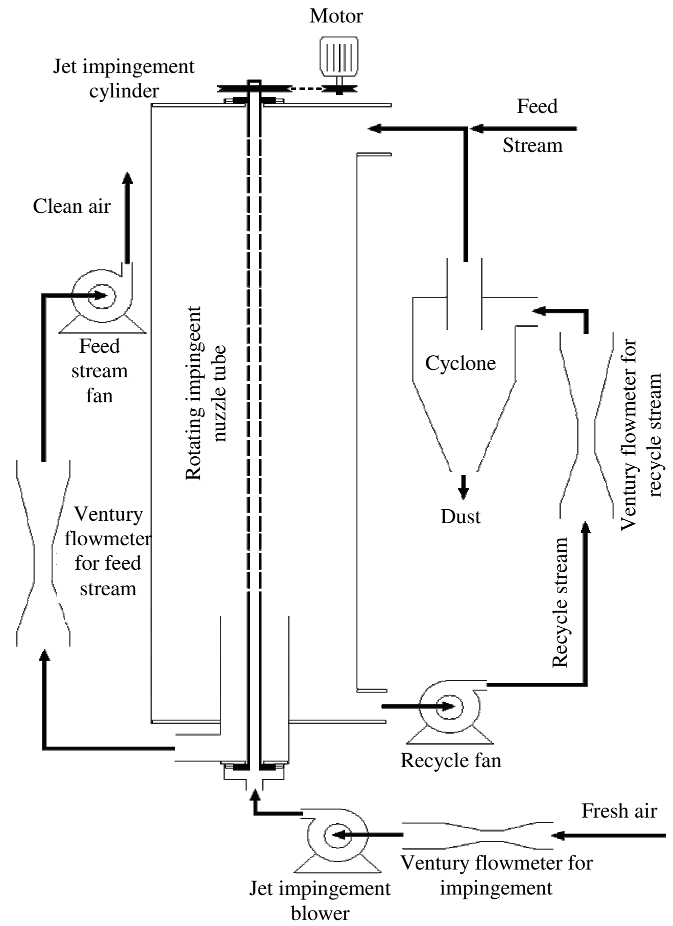

Fig. 1: Jet impingement-recycling cyclone dust separating Process with dividing chamber feed input design.

the efficiency of cyclones by introducing either improved design and operating variables or by new modifications in the design of the equipment [1]. An auxiliary device called Post Cyclone (PoC) was introduced and tested for its ability to reduce the emissions of fines from industrial cyclones [2, 3]. In order to increase the efficiency of conventional cyclones, a double cyclone both with and without electric field has been proposed and tested [4]. Another recent innovation for improving the collection efficiency is the use of a centrifugal impeller inside the cyclone in place of the immersion tube for the purpose of improved repulsion of the dust escaping from the cyclone [5]. Also, the idea of (PoC) had been tested as a recycle stream from the outlet stream to the feed stream of the cyclone in order to give another chance to the particles to become separated by the cyclone. In this method an especial design chamber were used for dividing the outlet dust included gas stream from the cyclone into two streams [6]. In the design of the chamber it was tried to take the benefits of increasing the concentration of particle dusts in the recycle stream compared to the cleaned out stream which are both taken from the dividing chamber. In this way significant improvements in removal efficiency of the cyclone were obtained.

In this paper the impact of modification is put on the design of the dividing chamber of the idea in [6]. The dividing chamber is used for dividing a dust entrained gas stream into two streams; one with higher particle concentration and the other with lower particle concentration. The low concentration stream is considered as cleaned-out stream from the overall dust separating process. The high concentration one is sent back to cyclone for dust removal and the cleaned out stream from the cyclone also is recycled back and mixed with the feed to the dividing chamber. A flow diagram is shown in Fig. 1 for the proposed dust separating process. A rotating tube is installed inside

Table 1: The coded and un-coded design factors for the three variables.

-1.6818	-1.0	0.0	1.0	1.6818	Design Factors
0.16	0.3	0.5	0.7	0.84	X_1=Feed flow/Max. Feed Flow
0.16	0.3	0.5	0.7	0.84	X_2 = Recycle flow/Max. Recycle Flow
0.0	0.178	0.44	0.7	0.88	X_3 = Jet flow/Max. Jet Flow

the dividing chamber for providing radial jet-impingement streams for throwing and concentrating the particles in a zone near to the wall of the cylindrical chamber. This process is called here jet-impingement-cyclone-recycling dust separator.

The required flow meters and fans are also shown in this figure. The outlet stream from the impingement nuzzles that are drilled around the impinging tube, located inside the cylindrical chamber is entered from the lower part of the nuzzle tube. The more concentrated stream flows from the annular section in the lower part of the impingement chamber and the less concentrated clean stream enters the internal duct. The impinging jets around the rotating inner tube which are fed by clean air should be designed such that it works more effective in throwing particles and putting them much far from the axis of the tube. The jet-impingement-recycling cyclone dust separating process introduced in this paper can be considered to be much effective than a cyclone de-duster alone provided that it is designed as a cyclone feed input process instead of the chamber feed input design which is shown in Fig. 1. However, the chamber feed input scheme in Fig. 1 is used in this paper since the objective of the paper is to test the performance of the chamber alone.

EXPERIMENTAL SECTION

A pilot scale apparatus was designed and built for obtaining data. Two cyclones of stairmand design with cylindrical diameter equal to 15 cm was used with a jet-impingement diameter of 30 cm including 300 nuzzles of 6 mm diameter, used around the nuzzle tube. The effective light of the chamber is 144 cm. The effective height is from the lower rows of nuzzles on the tube up to the ceiling of the chamber, where the upper row of nuzzles are drilled. The apparatus was tested according to CCD (Central Composite Design) experimental design method. For this purpose 20 experiments for variation of three variables including: feed flow rate, recycle flow rate and jet-impingement flow rate were conducted. By CCD experimental method optimal operating conditions can also be explored from the data. The following three dimension model is used for multi regression analysis for obtaining the optimum values of the three variables.

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_{11}X_1^2 + B_{22}X_2^2 + B_{33}X_3^2 + B_{12}X_1X_2 + B_{13}X_1X_3 + B_{22}X_2X_3 \quad (1)$$

The coefficients, B_i must be evaluated according to the set of data. The factors X_i are the design factors that are introduced in Table 1.

The design matrix is also shown in Table 2.

The maximum values of the flow variables including feed flow, recycle flow and jet-impingement flow, mentioned in Table 1 are as: 363.8, 512.6 and 303.7 cubic meter per hour, respectively.

In order to improve the precision of data the experiments were repeated four times for each one. The results of calculation of errors for different cases of inclusion of interaction coefficients of the regression analysis in (1) are summarized in Table 4. The results show that inclusion of all coefficients (the lowest row of the Table 4) gives the least error of regression.

Fig. 2 through 4 show the effects of each variable on the efficiency at a constant amount of the other variables. The operating point selected in the above figures is: X_1=358.0 m^3/hr, X_2=159.9 m^3/hr, X_3=76.9 m^3/hr. Since that the total input air flow rate to the chamber is equal to the sum of the above three input flow rates; then, increase of each of them, with the other two being constant, means that the total input flow rate to the chamber is increasing. Fig. 2 shows a decrease in efficiency with increase of feed flow rate, while the other two are representing the appearances of minimum and maximum points with increase of recycle and jet-impingement flow rates,

Table 2: Design matrix.

Run	BLK	A	B	C
1	1	-1	-1	-1
2	1	-1	-1	1
3	1	-1	1	-1
4	1	-1	1	1
5	1	1	-1	-1
6	1	1	-1	1
7	1	1	1	-1
8	1	1	1	1
9	1	-1.6818	0	0
10	1	1.6818	0	0
11	1	0	-1.6818	0
12	1	0	1.6818	0
13	1	0	0	-1.6818
14	1	0	0	1.6818
15	1	0	0	0
16	1	0	0	0
17	1	0	0	0
18	1	0	0	0
19	1	0	0	0
20	1	0	0	0

Table 3: The results of experiments for feed from jet-impingement chamber.

Efficiency	Jet flow/Max. Jet Flow	Recycle flow/Max. Recycle Flow	Feed flow/Max. Feed Flow	Number of Experiments
93.64	-1	-1	-1	1
94.86	0	0	0	2
94.63	1	-1	-1	3
94.68	-1	1	-1	4
95.18	0	0	0	5
94.99	1	1	1-	6
95.52	-1	-1	1	7
94.00	0	0	0	8
90.23	1	1	1	9
95.72	-1	1	1	10
94.68	0	0	0	11
96.43	1	1	1	12
95.10	0	0	-1.6818	13
94.25	0	0	1.6818	14
96.17	0	0	0	15
92.03	0	-1.6818	0	16
96.68	0	1.6818	0	17
94.18	-1.6818	0	0	18
96.39	1.6818	0	0	19
94.69	0	0	0	20

Table 4: The results of regression analysis and fitting of Eq. (1) to data.

B_0	B_1	B_2	B_3	B_{11}	B_{22}	B_{33}	B_{12}	B_{13}	B_{23}	Resnorm
1.673427	0.476701	0.096387	0.004333	-0.00067	-0.00022	-7.2E-05				0.00326
1.539837	0.512036	0.062895	-0.08539	-0.00072	-0.00025	-9E-05			0.000575	0.00310
2.102578	0.489276	0.065483	0.000942	-0.00066	-0.00026	0.000132	-0.00033		0.000566	0.00305
2.3359	0.482624	0.81703	-0.01038	-0.00063	-0.00025	0.000132	-0.00033	-6.5E-5	0.000625	0.00300

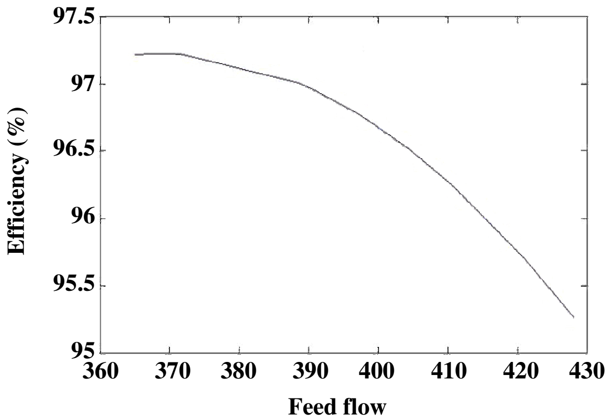

Fig. 2: Effect of feed flow rate on efficiency at constant Jet-impingement and recycle flow rates, Recycle flow rate=159.9 m^3/h, Jet flow rate=76.9 m^3/h.

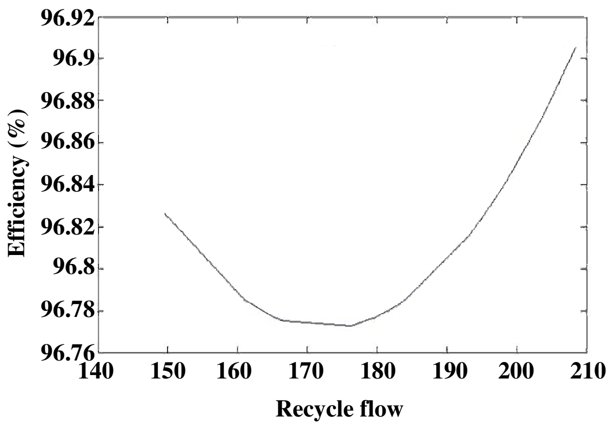

Fig. 3: Effect of recycle flow rate on efficiency at Constant jet-impingement and feed flow rates, Feed flow rate=358.0 m^3/h, Jet flow rate=76.9 m^3/h.

respectively. The increase of efficiency with increase of recycle rate is a known phenomenon which is confirmed in previous studies [6]. However, the minimum point appearing here in Fig. 3 can be explained in view of the effect of jet-impingement effect. On the other hand, the decreasing characteristic of Fig. 2 can be explained similarly, since that by increase of feed flow rate, at constant recycle flow rate, the recycle ratio decreases. Also, concerning the maximum point appearing in Fig. 4, the most appropriate conclusion is that the jet-impingement imposes a positive effect but with some maximum limitation, after which its effect reverses.

CONCLUSIONS

A new dust removing process for cleaning industrial gas streams is proposed in this paper which helps in improving cyclone efficiency. It makes use of jet-impingement flow effects on particle displacement in radial direction when the dusty flow is passing through a cylindrical chamber. In this way the particle concentration profile will become shifted towards the higher radius and brings about the possibility of removing the majority of particles by use of a recycle stream taken from the annular section in the bottom of the chamber. On the other hand, the recycle stream itself is affecting on the improvement of the overall efficiency of the apparatus. The recycling technique had been used previously in another paper. In the present paper in order to improve the effects of recycling technique the length of the dividing chamber was increased. This helps in giving the particles more retention time inside the chamber for being located nearer to the wall of the chamber. The experiments conducted on a pilot scale of the apparatus showed that while the recycle stream increases the overall efficiency of the process, meanwhile it shows a minimum point at low recycle rates due to the effect of jet-impingement stream. However, the jet-impingement itself represents a maximum point on efficiency. An optimum obtained from the experiment results was:

Optimum efficiency = 97.58%

At:

Feed flow rate/maximum feed flow rate = 0.8364

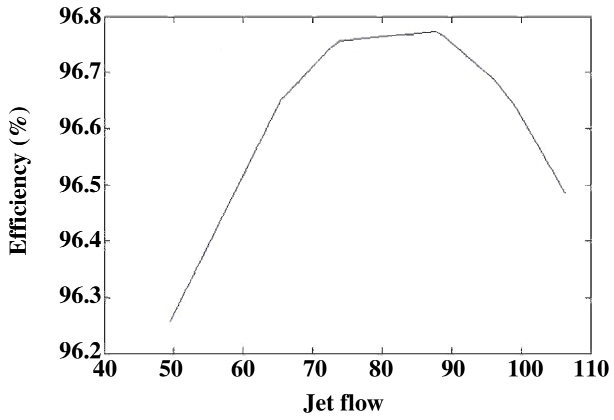

Fig. 4: Effect of jet-Impingement flow rate on Efficiency at constant feed and recycle flow rates Recycle flow rate=159.9 m^3/hr Feed flow rate=358.0 m^3/hr.

Recycle flow rate/maximum recycle flow rate=0.8364

Impingement flow rate/maximum impingement flow rate=0.42.

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