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Original Paper

Performance Augmentation and Cost Minimization of Pollution Control Device by Value Engineering Techniques

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Abstract *- Wet scrubbers are highly effective devices for controlling air pollution, primarily utilized in industrial exhaust streams. The operation of a wet scrubber involves spraying the contaminated gas stream with a scrubbing liquid, typically water. This research article presents a case study that employs value analysis techniques to reduce costs and enhance the performance of wet scrubbers. The functions of individual components of the wet scrubber are analyzed, and the critical component contributing to performance loss is identified using the Function-Cost-Worth-Analysis (FCWA) matrix. The spray nozzle is identified as the critical component with a high-value index. The issue is determined to be the inadequacy in the spray area of the scrubbing liquid, which allows flue gases to escape, thereby reducing the scrubber's performance. The proposed solution involves increasing the spray area by changing the nozzle type and redesigning the nozzle positions. Although this solution results in a higher cost compared to the old design, cost reduction is achieved by altering the nozzle material. The proposed solution is validated using Computational Fluid Dynamics (CFD) and structural Finite Element Analysis (FEA). The validation results indicate an 11.5% increase in performance and a 2.52% reduction in the cost of the wet scrubber.*

Keywords *- Value analysis, FAST diagram, FCWA matrix, CFD, Structural FEA, Evaluation matrix.*

1. Introduction

Value Analysis (VA) or Value Engineering (VE) is a technique with a well-structured, multi-disciplinary methodology to recognize and resolve issues to enhance the performance of the product and minimize the overall cost of the product. The product value could be inferred in various methods with different consumers. The common points of value engineering are getting maximum performance, demonstrative demand, competence, and smartness related to the cost of the product [1, 2]. Value is nothing but acquiring the maximum reliability in the function of the product with a minimum cost, which infers to obtaining the maximum performance with higher quality. The main objective of modern value engineering is to provide an essential role to the consumer with the lowest cost of the product. The system of functional analysis is influential in reaching customers' needs at minimum cost. This tool is preferred by top management because it is used to identify and eliminate unwanted costs without affecting the quality aspects of the product, including its functions and services. To avoid the wrong decisions of an individual approach, this method is promoted with a multidisciplinary team approach and proceeds with a systematic data collection procedure from reliable assets. This research work deals with the problem of performance improvement of a pollution control device, a wet scrubber, which is used in the foundry industry. Hence, value analysis is used to improve the enactment of a wet scrubber at the lowest possible cost.

2. Literature Survey

Value engineering is a technique to improve the values of the products by enhancing their functions and avoiding cost increases. VE focuses on customer requirements with a function-cost approach that is customer-oriented [3-5]. VE can be employed at any number of times during the project's design and development at any interval. Nevertheless, the maximum value could be obtained in the initial stage of development and theoretical design phases [6, 7].

The application of value engineering theories and methods in the industry was presented. They demonstrate how value engineering, through its various phases, can be applied to any product to reduce costs. The selection of materials is done in such a way that the cost is minimized without compromising the product's value and design [8, 9].

To identify the best possible alternatives, tools such as function analysis, functional evaluation, and decision matrix are utilized, providing the most suitable results. The fundamentals of value engineering and its various phases that can be implemented to optimize a product were presented [10-12]. A case study demonstrated how product costs can be minimized through the application of value engineering methodology. Several worksheets were developed, and a thorough analysis was conducted to arrive at a concrete solution [6]. VE can be executed in different stages of production, from the raw material to the final product, to minimize the overall cost of the product. The material may be selected at a low cost without affecting the overall value of the final product and its design. To find the best probable alternative from the choices, it could be better to use other tools like function analysis, functional evaluation, and decision matrix to give the most suitable outcomes [13-15].

A case study revealed how to use the systematic value methodology in the area of production and design stages. The results were achieved by adhering to a step-by-step methodology of identification and evaluation of functions before generating the ideas and deferring the judgment till the creation process was completed [16]. The application of the value analysis technique was investigated to achieve about a 15% reduction in material costs for the products. Through data collection and analysis, they identified the vehicle areas or subsystems with the greatest potential for cost reduction. Value engineering and value analysis are used to accomplish using a job plan, lean approach, PDCA, industry 4.0, etc. [17, 18]. Based on the above literature, the problem of the case study was identified, and the appropriate methodology was adopted.

3. Methodology

The research methodology starts with a detailed process reading of the company, and after more analysis, the appropriate problem was identified. The value engineering practice elaborates on the value of job plan practice and the flow chart used in this examination study. Figure 1 shows the methodology followed in the study. The study starts by finding the problem in the exciting process and finding the objective of the research. Then, the different stages of the analysis covered in the study are carried out to find the results. Finally, the discussion was made to conclude.

4. Design of Work with Data Collection and Analysis

The design of work is a methodical deed to conduct a value engineering study and to assume the execution of the appropriate commendations. This research work covers the following six-stage design of work, starting with data collection and ending with the recommendation stage. The job plan is a systematic and organized approach for conducting a value engineering analysis and implementing the resulting recommendations. This project comprises a six-phase job plan as follows:

- Data
- Role
- Formation
- Investigation
- Evaluation and
- Recommendation

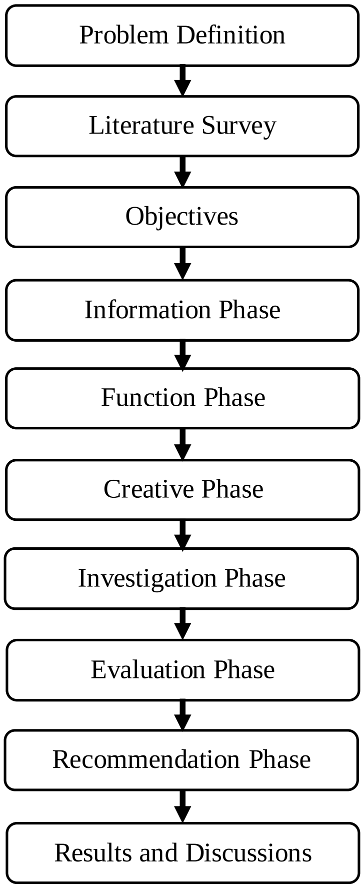

Fig. 1 Methodology flow chart

5. Data Stage

In this stage, the existing practices were clearly studied, and the entire data collected pertaining to arch to continue the VE investigations.

The wet scrubber device is used to remove pollutants in the exhaust stream. The cost of the existing wet scrubber is Rs.6,15,500. There are 65 gunmetal flat fan nozzles used in the existing model.

The wet scrubber's design information, specifications, and cost details were collected. The components of the wet scrubber were identified. In addition, discussions were held with purchase, design and material engineers for more details about the wet scrubber. The side view of the wet scrubber setup is shown in Figure 2.

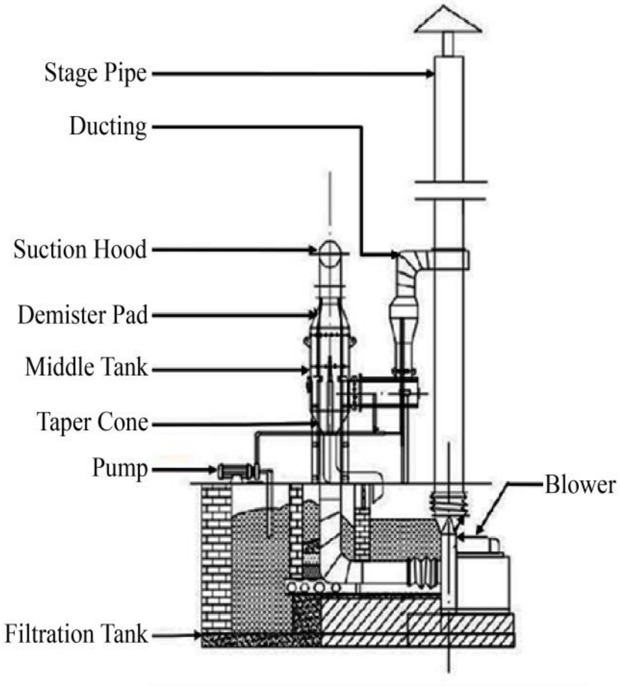

Fig. 2 Wet scrubber setup

6. Role Stage

Once the relevant data has been collected, all the functions of the components of the wet scrubber are identified in this phase. The middle tank performs the basic function of wetting the scrubber (removing pollutants). The feature function matrix for the middle tank is developed and shown in the following Table 1.

The Function Analysis System Technique (FAST) diagram is used to identify the higher-order function, basic function, secondary function and lower-order function of a product or service. The technical FAST diagram for the pollution control device of the wet scrubber is shown in Figure 3.

The function cost worth analysis matrix is used to identify the value gap or value index of product components. The FCWA matrix for the middle tank is shown in Table 2 with the value index and the corresponding rank. On analyzing the FCWA matrix, it is found that the component of the nozzle has the highest value index. Hence, new ideas are generated for the nozzle in the creative phase. The graphical representation of the value index is shown in Figure 4.

Table 1. Feature function FCWA matrix

Middle Tank (Blower Connecting Tank)	Cylinder	Thread	Arrest	Motion	S
			Join	Components	S
		Coating	Prevent	Corrosion	S
		Thickness	Improve	Strength	S
		Diameter	Retain	Liquid	B
		Length	Hold	Liquid	S
	Flat Ring	Thickness	Prevent	Leakage	B
		Inner Diameter	Allow	Liquid	S
		Outer Diameter	Accommodate	Shape	S
	Coupling	Diameter	Allow	Pipe	S
		Length	Accommodate	Pipe	S
		Thread	Join	Components	B
			Arrest	Motion	S
		Coating	Prevent	Corrosion	S
	Water Spray Nozzle	Major Diameter	Receive	Water	S
		Minor Diameter	Increase	Pressure	B
			Delivery	Water	S
		Length	Transfer	Water	S
		Thickness	Withstand	Pressure	S
	Upper Flange	Inner Diameter	Provide	Flow	S
		Outer Diameter	Accommodate	Shape	S
		Thickness	Improve	Strength	S
		Hole	Accommodate	Parts	S
			Join	Parts	B

	Lower Flange	Inner Diameter	Provide	Flow	S
		Outer Diameter	Accommodate	Shape	S
		Thickness	Improve	Strength	S
		Hole	Accommodate	Parts	S
			Join	Parts	B
	Reducer	Major Diameter	Receive	Water	S
		Major Diameter	Delivery	Water	S
			Reduce	Volume	B
		Thickness	Withstand	Pressure	S
		Thread	Join	Components	S
	Round Pipe	Diameter	Retain	Water	S
		Length	Transfer	Water	B
	T-bend	Bend	Change	Direction	B
		Length	Transfer	Water	S
		Diameter	Retain		S
		Coating	Prevent	Corrosion	S
	Rubber Washer	Inner Diameter	Allow	Bolt	S
		Outer Diameter	Accommodate	Shape	S
		Thickness	Seal	Gap	B
	Bolt	Diameter	Accommodate	Hole	S
		Length	Join	Components	B
		Thread	Arrest	Motion	S
		Coating	Prevent	Corrosion	S
	Nut	Diameter	Allow	Bolt	S
		Length	Enhance	Handling	S
			Join	Components	B

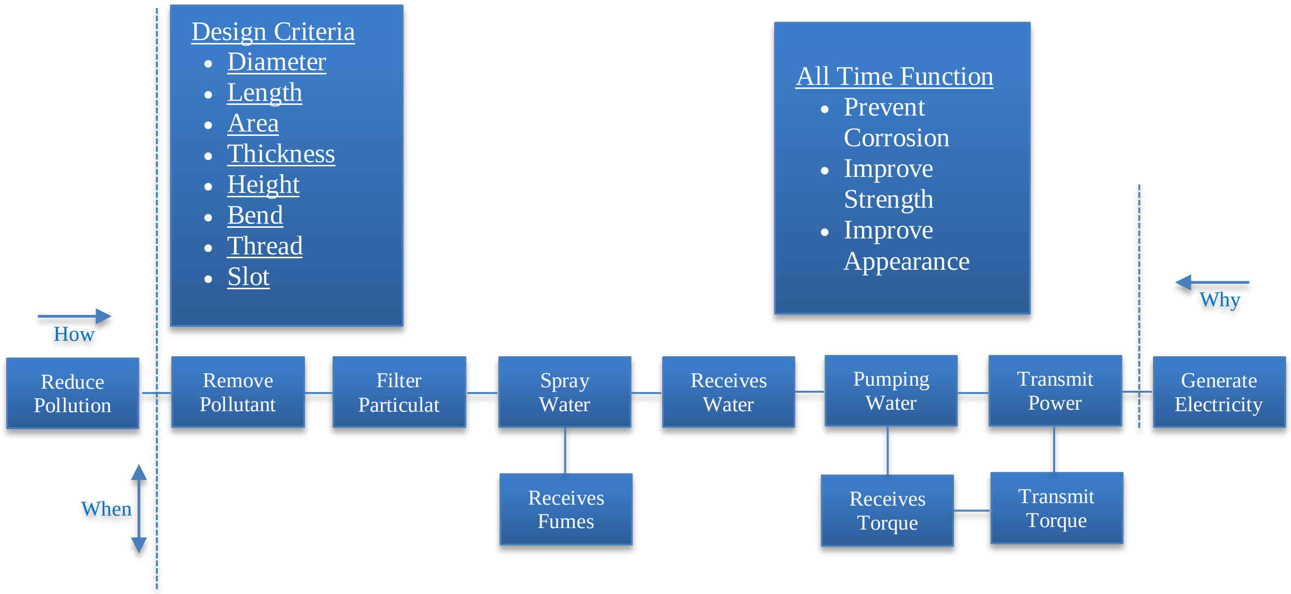

Fig. 3 FAST diagram of wet scrubber

Table 2. FCWA matrix

Component	Function		Existing Cost (Rs.)	Worth (Rs.)	Value Index	Rank
	Verb	Noun				
Body	Retain	Liquid	5509	671.8	8.2	2
Gasket	Prevent	Leakage	6	6	1	9
Coupling	Join	Components	184	47.05	3.91	5
Upper Flange	Join	Parts	334	78.40	4.26	4
Lower Flange	Join	Parts	480	61.54	7.79	3
Reducer	Reduce	Volume	65	39	1.67	6
Nozzle	Spray	Water	420	50	8.4	1
T Bend	Change	Direction	90	57	1.57	7
Water Spraying Pipe	Transfer	Water	483	335	1.44	8
Bolt	Join	Components	4.50	4.50	1	10
Nut	Join	Components	3.30	3.50	1	11

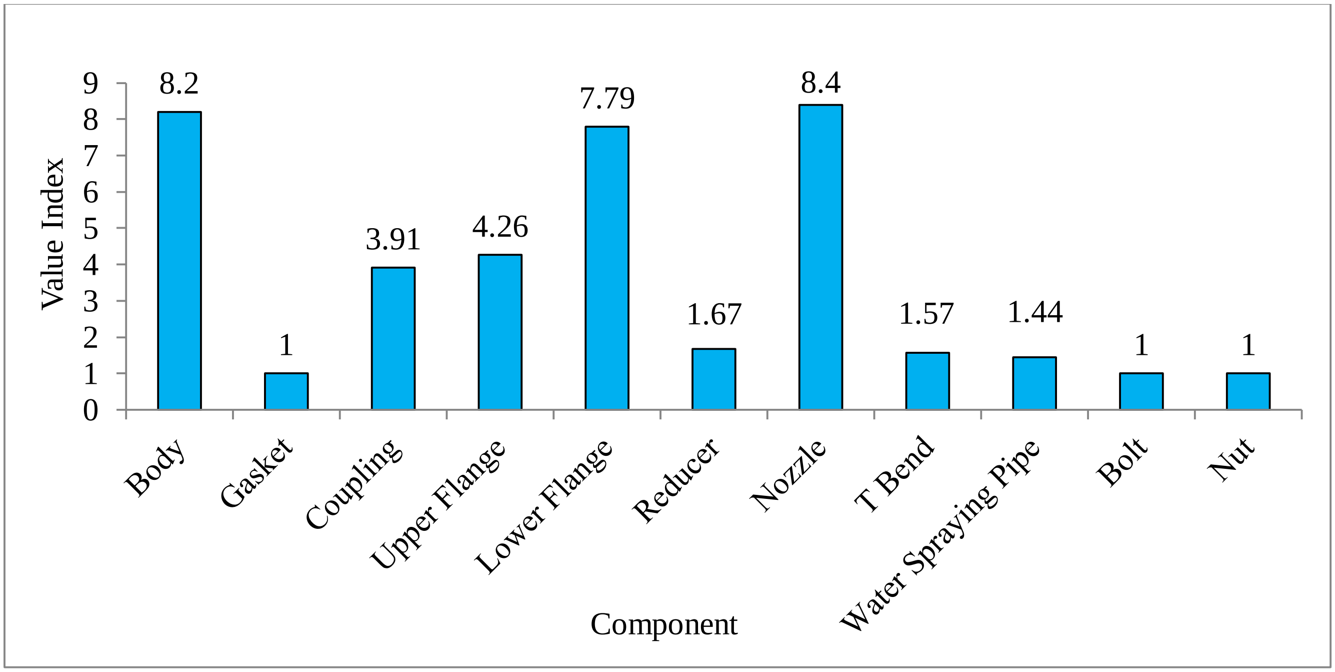

Fig. 4 Value index

7. Formation Stage

In this stage, new concepts and notions are developed to enhance the overall performance and to reduce the cost of the wet scrubber using brainstorming techniques. These are the ideas generated for the nozzle through a brainstorming session.

- Change material to Aluminum
- Change material to Stainless steel
- Change material to Polypropylene
- Change material to Mild steel
- Change type to Atomizing Nozzle
- Change type to Hollow Cone Nozzle
- Change type Full Cone Nozzle
- Change type Flat Spray Nozzle
- Arrangement of the nozzle in a circular pipe
- The nozzle is attached to the inner circumference.

8. Investigation Phase

The existing scrubber's performance is analyzed using CFD. The proposed CAD model is developed with CATIA and is shown in Figure 5. The different boundary values with various parameters on CFD analysis are given in Table 3.

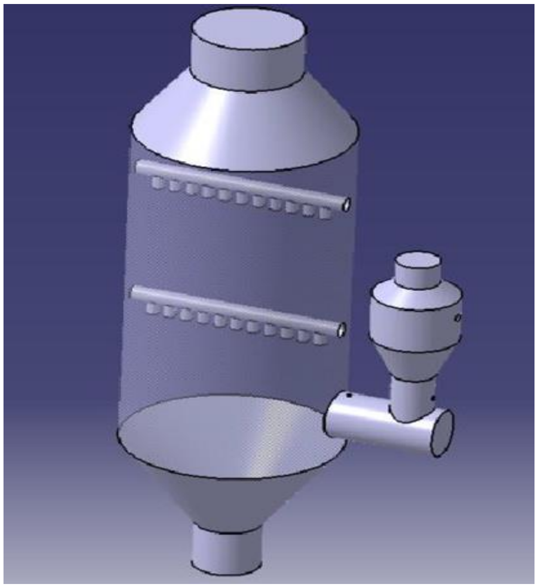

Fig. 5 Existing wet scrubber

Table 3. Boundary conditions for CFD analysis

Boundary	Boundary Type	Value
Flue Gas Inlet	Velocity Inlet	Velocity -7.5m/s Pressure-1 atm (101325 Pa) Flue gas mass fraction – 0.8
Water Inlet	Velocity Inlet	Velocity – 20m/s Pressure – 40 psi (275790.28 Pa)
Filtered Gas Outlet	Pressure Outlet	Pressure – 1 atm (101325 Pa)
Waste Outlet	Pressure Outlet	Pressure – 1 atm (101325 Pa)

The performance of the wet scrubber is analyzed for the existing design using the boundary conditions shown in Table 3. The CFD analysis is carried out using ANSYS R18.0 with a contour plot of the flue gas mass fraction of the existing wet scrubber, as shown in Figure 6.

The efficiency of the existing wet scrubber is calculated using Equation (1). The efficiency results calculated for the existing model are represented in Table 4. The efficiency is influenced by the type of nozzle and the arrangement of the nozzle inside the scrubber.

$$Efficiency = 1 - \frac{\textbf{\textit{Ouput mass fraction of flue gas}}}{\textbf{\textit{Input mass fraction of flue gas}}} \quad (1)$$

Table 4. Efficiency calculation

Model	Existing
Flue gas mass fraction at the inlet	0.8
Flue gas mass fraction at the outlet	0.29
Efficiency (%)	63.75

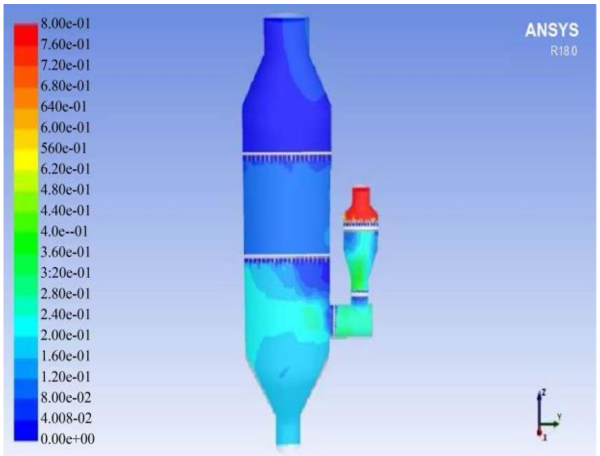

Fig. 6 Contour plot of flue gas mass fraction of existing wet scrubber

9. Evaluation Stage with Results

This assessment stage could minimize the pool of concepts developed during the formation stage methodically so that some of the concepts may meet the original research goals. The analysis is to be carried out with the final results of probable substitutes to find their apparent merits, aids, and also their risk factors.

The first step towards evaluation is to identify various parameters for judging the ideas shortlisted, while the parameters are decided based on the requirements of the project. The next step is fixing each parameter's weight through a rational and objective technique. The different parameters for the nozzle with the respective key letters are shown in Table 5.

Table 5. Parameters for a nozzle

Parameter	Key Letter
Spray Pressure	A
Spray Pattern	B
Reliability	C
Drop Size	D
Spray Distance	E

The preset method is to be used to compare the parameters of the nozzle. The different steps recommended in this method are

- Each parameter of the nozzle should have 100 points.
- The team has to decide the minimum point of acceptance for each parameter, and the final points awarded are shown in Table 6.
- The total number of paired comparisons should be 10 [5x (5-1)/2].
- The maximum points to be allocated to one pair are 17.5 (175/10), where 210 are the total remaining points.
- The remaining points have to be distributed through a quantitative method, and the scores are shown in Table 7 of the matrix.

Table 6. Allocation of points

Parameter	**Key Letter**	**Maximum Points**	**Minimum Points**	**Remaining Points**
Spray Pressure	A	100	50	50
Spray Pattern	B	100	80	20
Reliability	C	100	72	30
Drop Size	D	100	60	40
Spray Distance	E	100	65	35
Total		500	325	175

Table 7. Quantitative method matrix

	A	C	D	E	Total Score
A	A=7 B=10.5	A=7.5 C=10	A=6 D=11.5	A=8 E=9.5	28.5
B		B=11.5 C=6	B=9 D=8.5	B=10 E=7.5	41
C			C=8.5 D=9	C=5 E=12.5	29.5
D				D=9 E=8.5	38
E					38

- The final score has been calculated by adding the least preset points and points arrived at through paired comparison. The percentage of each parameter has been calculated, and the final results are shown in Table 8.
- The final score of the parameters is used in the construction of the evaluation matrix. In the matrix columns, the parameters are assigned along with their Weights. In the matrix rows, all the alternatives and the existing ones are placed. Alternatives, as well as existing ones, are evaluated against each parameter on a five-point scale, as given in Table 9.
- The final step, after allocating points to each alternative and the existing components, the ranking has been made. The evaluation matrix is shown in Table 10.

Table 8. Final score

Parameter	**Predetermined Minimum Points**	**Points Arrived through Paired Comparison**	**Final Score**	**% of Weights**
Spray Pressure	50	28.5	78.5	15.7
Spray Pattern	80	41	121	24.2
Reliability	70	29.5	99.5	19.9
Drop Size	60	38	98	19.6
Spray Distance	65	38	13	20.6
Total	325	175	500	

Table 9. Five-point scale rating

Outstanding	5
Very Good	4
Noble	3
Reasonable	2
Meager	1

Table 10. Evaluation matrix

Parameters **Achievers**		**A**	**B**	**C**	**D**	**E**	**Total Points**	**Rank**
		15.7	**24.2**	**19.9**	**19.5**	**20.6**		
Flat Fan Nozzle	5						318.7	7
	4			*				
	3	*	*		*	*		
	2							
	1							
Total		47.1	72.6	78.4	58.8	61.8		
Full Cone Nozzle	5		*		*		443.8	1
	4	*		*		*		
	3							
	2							
	1							
Total		62.8	121	79.6	98	82.4		
Hollow Cone Nozzle	5						183.7	4
	4							
	3		*					
	2	*			*			
	1			*		*		
Total		31.4	72.6	19.9	39.2	20.6		
Hollow Cone Nozzle	5	*				*	377.5	2
	4		*	*				
	3							
	2							
	1				*			
Total		78.5	96.8	79.6	19.6	103		

On analyzing the evaluation matrix, it is found that the full cone nozzle is the best alternative solution. To improve coverage of the spray area inside the scrubber, the arrangement of nozzles has been changed, which requires more nozzles. In the existing model, the gunmetal material is used for nozzles and increasing the number of nozzles will also increase the cost if the same material is used. To address this problem, different materials for the nozzle are analyzed using structural FEA. The results of boundary conditions for structural FEA are given in Table 11.

Table 11. Boundary conditions for structural FEA

Boundary	**Value**
Nozzle tap	All DOF fixed
Nozzle inner walls	Axial pressure – 40 psi (275790.298 Pa)

The CAD model developed for the full cone nozzle is shown in Figure 7. Similarly, the CAD model is discretized using Hyper Mesh, as shown in Figure 8. The results of FEA for different materials such as gunmetal, stainless steel, aluminium and polypropylene are shown in Figure 9.

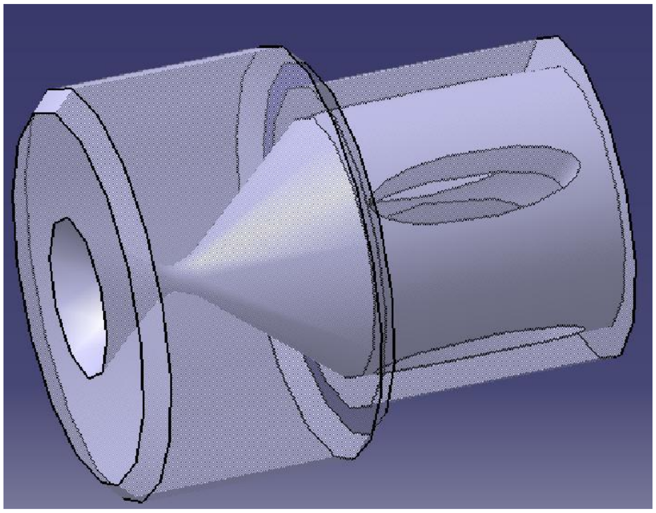

Fig. 7 CAD model of full cone nozzle

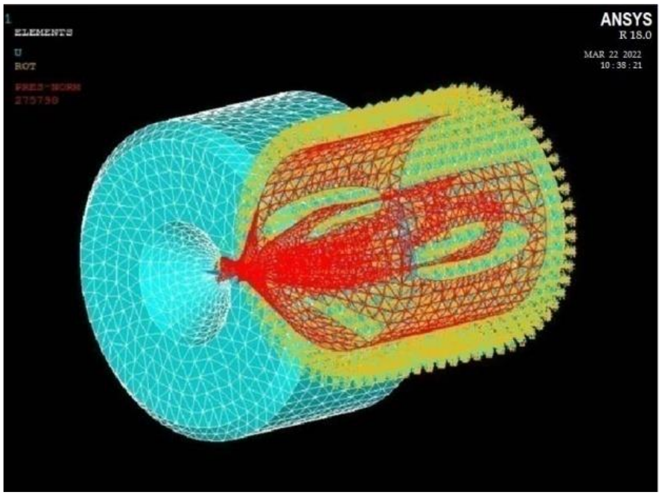

Fig. 8 Discretized model of full cone nozzle

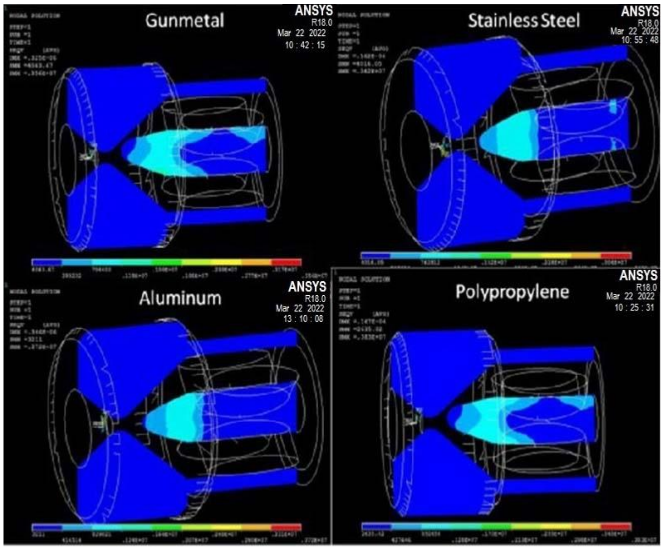

Fig. 9 Results of FEA for different materials

The factor of safety of the nozzle for all the materials mentioned above is calculated, and the final results are represented in Table 12. The allowable factor of safety for the spray nozzle is 3.5 to 6. From the results of Table 12, it is observed that the polypropylene is sufficient to be used as the nozzle material in the scrubber. The cost of polypropylene is much less than that of gunmetal. Therefore, a polypropylene nozzle offers a better alternative solution to reduce the cost of a wet scrubber.

Table 12. Factor of safety

Material	**Actual Stress (x10^6 N/m^2)**	**Ultimate Stress (x10^6 N/m^2)**	**Factor of Safety (No Units)**
Gun Metal	3.56	310	87.08
Poly-propylene	3.83	33	8.62
Stainless Steel	3.42	370	111.11
Aluminum	3.75	338	90.13

10. Recommendation Phase with Discussion

In the proposed model, there are 102 polypropylene full cone nozzles arranged in concentric pipes. Based on the alternative solution, a new wet scrubber design is proposed. The CAD model is created in CATIA and is shown in Figure 10. The boundary conditions for CFD analysis are given in Table 3. The performance of the wet scrubber is analyzed for the proposed design using the boundary conditions, and the results are given in Table 3. The ANSYS software is used for CFD analysis, as shown in Figure 11.

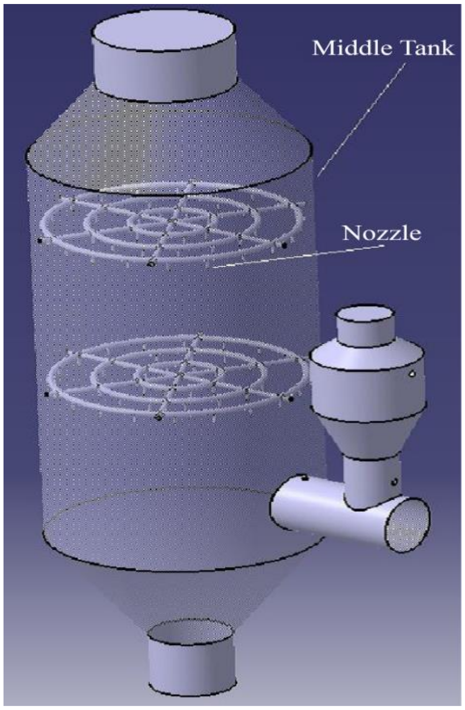

Fig. 10 Proposed CAD model

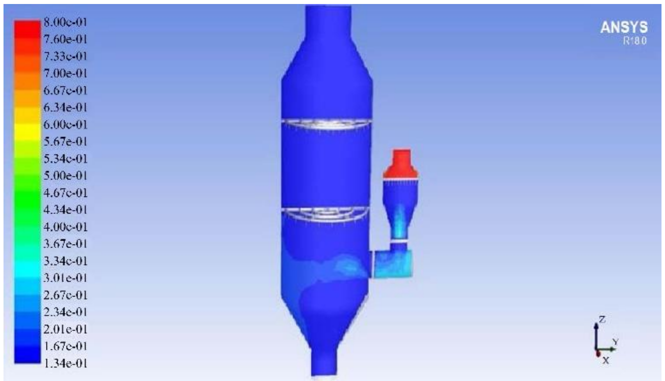

Fig. 11 Contour plot of flue gas mass fraction of proposed wet scrubber

The efficiency of the proposed model is calculated, and the final observed results are presented in Table 13. Similarly, the overall results of cost reduction and the efficiency of the wet scrubber before and after applying value analysis are given in Table 14.

Table 13. Efficiency of the proposed model

Model	Proposed
Flue gas mass fraction at the inlet	0.8
Flue gas mass fraction at the outlet	0.198
Efficiency (%)	75.25

Table 14. Overall results obtained before and after applying VA on the wet scrubber

Model	Existing	Proposed
Flue gas mass fraction at the inlet	0.8	0.8
Flue gas mass fraction at the outlet	0.29	0.198
Efficiency (%)	63.75	75.25
Type of nozzle	Flat Fan	Solid
Nozzle Material	Gun Metal	Polypropylene
No. of nozzles	65	102
Cost per nozzle (Rs.)	435	92.4
Nozzle Cost (Rs.)	28,275	9424.80
Additional Tubing Cost (Rs.)	NA	3,320
Total nozzle cost (Rs.)	28,275	12,744.80
Total Cost (Rs.)	6,15,500	5,99,969.80

The cost of the wet scrubber before and after VE is shown in Figure 12. From the figure, it was observed that the cost was reduced by about Rs. 15,531 after the value engineering analysis.

The percentage of efficiency of the wet scrubber before and after VE is shown in Figure 13. From the results, it was found that the efficiency of the device increased by about 12%.

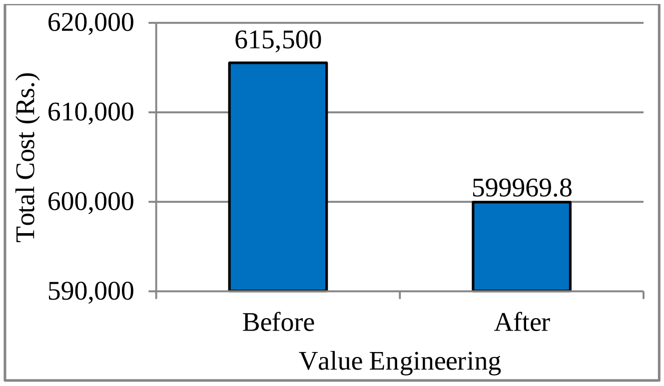

Fig. 12 Cost reduction of wet scrubber

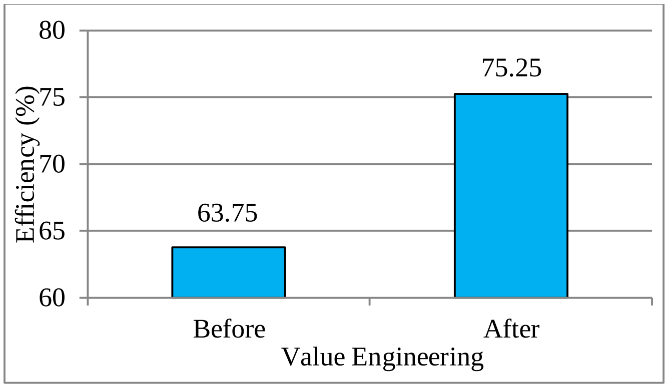

Fig. 13 Efficiency of wet scrubber

11. Conclusion

The research objective of value analysis is done for the pollution control device of a wet scrubber. A new nozzle arrangement model is proposed for the maximum value index found on the nozzle component. Based on the analysis and final observations, some of the following important conclusions were arrived at.

- The analysis of the evaluation matrix shows that the full cone nozzle is the best alternative solution for the proposed model.
- The efficiency of the proposed nozzle model is 75.25%, which is greater than the efficiency of the current model of 63.75%.
- The proposed nozzle cost is reduced to Rs. 12,744/- from the current nozzle cost of Rs. 28,275/-.
- The cost of the proposed pollution control device model is about Rs. 5,99,969/-, which is 2.52% less than the current wet scrubber cost.
- Value Analysis is an effective tool for eliminating unnecessary costs and increasing the functions of the device; hence, the overall value of the device is enhanced.

For further research, more different value engineering tools may be used to find the current value of the device and minimize the cost of the product.

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