KURDISTAN ENGINEERING UNION

Research on

Application of Venturi Blender by using Powell’s Conjugate direction optimization method

Prepared by: Ahmad Mohammed Hassan
September 2020

The aim of making this research to promotion from Licensed (qualified) to consultant

ABSTRACT

Optimization has a big role in industrial aspects therefore; it is the process of finding the greatest or least value of a function for some constraint, which must be true regardless of the solution. Alternatively, it means the best possible solution for a given problem under defined set of constraints. In this research can be seen that using Powell's Conjugate direction optimization method is a best method to optimize a venturi blender which shown in entire research. In this research analysing the problem then applying computation fluid dynamic CFD on the new constraints were explained. Finally the result for the final product of venturi blender was discussed and compared with other method.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

1- Introduction

Optimization has significant role in industrial and commercial applications. Optimization can be used to resolve any engineering application. As Rao (1996) pointed out that optimization could be defined as the procedure of determining the situations that lead to minimum or maximum value of function. In this report, the process of optimizing a Venturi Blender can be discussed by using Powell conjugate method.

Aims of the research are:

1- Optimizing the shape of the nozzle of Venturi Blender for maximum velocity and least turbulence.
2- Applying Powell's conjugate direction method on Venturi Blender model.
3- Comparing between new design model and reference model

1.1 Powell's conjugate direction method

Several methods are used to solve unconstrained minimization problems, one of the methods is pattern directions and it can be categorized as direct search method. Those problems could be avoided by alteration the direction of search in away rather than keep them always parallel to the coordinate axes. Techniques which use Pattern directions as search directions are called Pattern search methods. Powell's method is one of pattern search methods, therefore, in this method the objective function is quadratic and in two variables and unfortunately this method might not apply on multivariable functions even the function are quadratic. Powell's method can be used as a way of conjugate directions which minimizes quadratic function in a limit number of steps and Powell's method depends on function and function does not need to be differentiable or derivative would not be taken (Rao, 1996).

1.2 Nominal Venturi Blender

1.2.1 Problem analysis

Before any optimization process, it is very essential to know how to deal with boundary conditions of the system or model.As shown in figure 1, there are some constraints that it should be taken into account such as maximum permitted Oxygen consumption is 15 l/min, the mean velocity of the jet to get Reynolds number which should not be exceeded 3000 and back pressure not exceeding 2.8 bar at the inlet of Nozzle while maximising mixing. As well as there are three constraints could be used during regression equation process as shown in table-1.

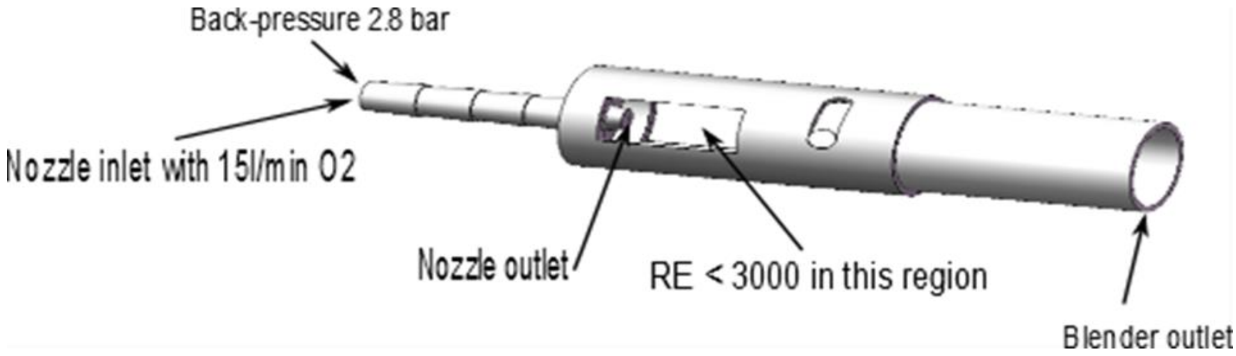

Figure 1: Venturi Blender

The red boxes show the real values of the venture blender before optimization study.

Constraints			
Diameter of Nozzle inlet D1	3 mm	5 mm	7 mm
Diameter of Nozzle outlet D2	1.3 mm	1.5 mm	1.7 mm
Outlet diameter of blender D3	18 mm	22 mm	26 mm

Table 1: constraint

1.3 Procedures

1.3.1Step 1: determining regression equation

In order to apply Powell's conjugate direction method to optimize venture blender model, it should be a function which can be minimized unto have the results. This function may create it by regression equation therefore; regression equation could be obtained by using Box-Behnken Design method and running 15 simulations on ANSYS CFD software program. As shown in table-2, it can be seen that a general factorial including a factor k= 3 and three levels which can be represented as +1 which represents maximum value and -1 which represents minimum value and 0 which indicates to average value. The design factors which shown as variables x1 and x2 are combined in two factors and numerically codes as +/- while, the third factor can be stayed immovable in centre. Regression equation can be written as a formula which could be shown in below. (Myers, Montgomery and Anderson-cook, 2009).

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum\sum_{i<j} \beta_{ij} x_i x_j + \epsilon$$

$$Re = -8531 + 868X_1 + 1626\,X_2 + 667X_3 - 29X_1^2 + 3831\,X_2^2 + 3X_3^2 - 131X_1X_2 - 547X_2X_3 - 6\,X_1X_3$$

Runs	factors												Response	
	Coded values			Actual value									Response	
	X1	X2	X3	D1	D2	D3	X1^2	X2^2	X3^2	X1X2	X2X3	X1X3	Reynold No.	velocity
1	-1	-1	0	3	1.3	22	9	1.69	484	3.9	28.6	66	2392	1.6
2	-1	1	0	3	1.7	22	9	2.89	484	5.1	37.4	66	2213	1.4
3	1	-1	0	7	1.3	22	49	1.69	484	9.1	28.6	154	3379	2.26
4	1	1	0	7	1.7	22	49	2.89	484	11.9	37.4	154	2990	2
5	-1	0	-1	3	1.5	18	9	2.25	324	4.5	27	54	2198	1.47
6	-1	0	1	3	1.5	26	9	2.25	676	4.5	39	78	1973	1.32
7	1	0	-1	7	1.5	18	49	2.25	324	10.5	27	126	3408	2.28
8	1	0	1	7	1.5	26	49	2.25	676	10.5	39	182	2990	2
9	0	-1	-1	5	1.3	18	25	1.69	324	6.5	23.4	90	2317	1.55
10	0	-1	1	5	1.3	26	25	1.69	676	6.5	33.8	130	2870	1.92
11	0	1	-1	5	1.7	18	25	2.89	324	8.5	30.6	90	3827	2.56
12	0	1	1	5	1.7	26	25	2.89	676	8.5	44.2	130	2631	1.76
13	0	0	0	5	1.5	22	25	2.25	484	7.5	33	110	2841	1.89
14	0	0	0	5	1.5	22	25	2.25	484	7.5	33	110	2841	1.89
15	0	0	0	5	1.5	22	25	2.25	484	7.5	33	110	2841	1.89

Table 2: applying Box-Behnken Design method

According to upper formula, there is equation which can be used as a function in venture blender problem in order to apply Powell's conjugate direction method for optimizing the shape of venture blender. The function can be written as shown in below. As well as the function can be represented as Reynolds number to determine the results.

1.3.2 Step 2: applying computation fluid dynamic CFD.

ANSYS CFD simulation software was used in order to determine regression equation and Reynolds number which may lead to have different values of velocities. As shown in figure-2, different values of design factors for venture blender could be applied by ANSYS simulation programme. Therefore; the boundary conditions which used during the process was limited such as Oxygen consumption should be 15 l/min, hence some assumption was set it for example; in order to avoid turbulent state, the velocity outlet should be assumed as 2 m/sec by applying Reynolds number equation on outlet diameter of blender,

$$Re = \frac{\rho V D}{\mu}$$

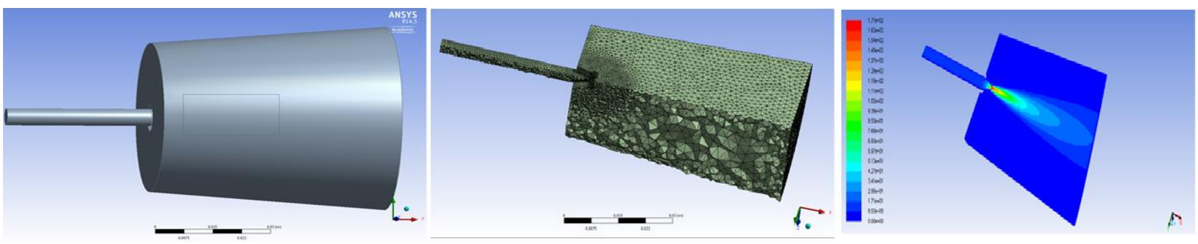

Figure 2: CFD model of Venturi Blender

Figure-2 shows cross section of geometry, mesh generation and solving the model during simulation after optimised the shape, velocity and Reynolds number.

As well as the range of velocities values in outlet of blender being between 1.32 and 2.56 m/sec as shown in figure 4. Thus, to minimize the inlet velocity of the nozzle to give less value of Reynolds number, it can be assumed as 5 m/sec during running the ANSYS simulation. The assumption which made about inlet velocity of nozzle has led to obtain different values of Reynolds number and velocities as shown in table-3

Runs	factors													
	Coded values			Actual value									Response	
	X1	X2	X3	D1	D2	D3	X1^2	X2^2	X3^2	X1X2	X2X3	X1X3	Reynold No.	velocity
1	-1	-1	0	3	1.3	22	9	1.69	484	3.9	28.6	66	2392	1.6
2	-1	1	0	3	1.7	22	9	2.89	484	5.1	37.4	66	2213	1.4
3	1	-1	0	7	1.3	22	49	1.69	484	9.1	28.6	154	3379	2.26
4	1	1	0	7	1.7	22	49	2.89	484	11.9	37.4	154	2990	2
5	-1	0	-1	3	1.5	18	9	2.25	324	4.5	27	54	2198	1.47
6	-1	0	1	3	1.5	26	9	2.25	676	4.5	39	78	1973	1.32
7	1	0	-1	7	1.5	18	49	2.25	324	10.5	27	126	3408	2.28
8	1	0	1	7	1.5	26	49	2.25	676	10.5	39	182	2990	2
9	0	-1	-1	5	1.3	18	25	1.69	324	6.5	23.4	90	2317	1.55
10	0	-1	1	5	1.3	26	25	1.69	676	6.5	33.8	130	2870	1.92
11	0	1	-1	5	1.7	18	25	2.89	324	8.5	30.6	90	3827	2.56
12	0	1	1	5	1.7	26	25	2.89	676	8.5	44.2	130	2631	1.76
13	0	0	0	5	1.5	22	25	2.25	484	7.5	33	110	2841	1.89
14	0	0	0	5	1.5	22	25	2.25	484	7.5	33	110	2841	1.89
15	0	0	0	5	1.5	22	25	2.25	484	7.5	33	110	2841	1.89

Table 3: applying Box-Behnken Design method

1.3.3 Step 3: Application of Powell's conjugate direction method

The conception of applying Powell's conjugate method is established on parallel subspace property which includes quadratic function which have found from regression equation and presents Reynolds Number and three variables D1, D2 and D3 with three directions of S. As well as, in application of Powell's conjugate method to venture blender, there was two factors which can be taken into consideration, maximum velocity and changing each of inlet and outlet diameter of nozzle D1, D2 and outlet diameter of blender D3 as illustrated in table-4.

SN.	D1 (mm)	D2 (mm)	D3 (mm)	Reynold No.	velocity m/sec
Initial dimensions	3	1.5	26	1973	1.32

Table 4: Initial dimension for applying Powell's conjugate method

The values which shown as in table-4, was taken as initial points. The suggestion was undertaken based on taking a minimum value of velocity which gives less Reynolds number and low velocity would be assured to avoid turbulent conditions and comfortable for patient who take the mixing of Air and Oxygen. The new design of venture blender could be obtained by applying Powell conjugate method as shown below,

Step1: from starting point put $(X^0)= [3,1.5,26]^T$ F(x^0) = 1973 ⟶ Velocity =1.32

Step 2: three independent directions could be selected such as $S^1 =[1,0,0]^T$,$S^2= [0,1,0]^T$,$S^3[0,0,1]^T$

The purpose of selecting these three directions is to converge from minimum point. As Kao, Li and Chen (2002) mentioned that Powell method can create direction to meet the minimum dimension as a result as well as to enhance the efficiency of action.

Step 3: λ could be determined as F(x^0+λS^2) was minimized, therefore $\frac{\partial F}{\partial \lambda}$ = 0, in order to to find λ

F(3,1.5, 26) + λ(0 ,1 ,0) ⟶ λ =0.19 ⟶ F(X^1)=1704.3=Reynolds number ⟶ Velocity = 1.25m/sec ⟶ (X^1) = (3, 1.69, 26)

Step 4: next iteration could be continued F $(X^1+\lambda S^1)$ ⟶ F (3, 1.69, 26) + λ (1, 0, 0) ⟶ F(3+ λ, 1.69, 26) was minimized, also ⟶ λ = 5.45 ⟶ F(X^2) = 2568.5 ⟶ velocity =1.72 m/sec ⟶ (X^2) = (8.45, 1.69, 26)

Step 5: iteration can be continued F $(X^2+\lambda S^2)$ ⟶ F (8.45, 1.69, 26) + λ (0, 1, 0) ⟶ F(8.45, 1.69+ λ , 26) ⟶ λ =0.098 ⟶ F (X^3) =2531.4 ⟶ Velocity = 1.69 m/s ⟶ (X^3) = (8.45, 1.79, 26)

Step 6: another iteration may be continued F $(X^3+\lambda S^3)$ ⟶ F(8.45, 1.79, 26) + λ (0, 0, 1) same step1,2,3 and 4, F(8.45,1.79, 26+λ) was minimized ⟶ λ =34 ⟶ F (X^4) = -1033 ⟶ velocity = -0.7 m/sec ⟶ (X^4) =(8.45,1.79, 60)

In this step, when lambda λ is a high value then the result would be in minus and it would be out of boundary conditions and it can't be feasible solution, although the direction in correct way therefor; the value of lambda could be assumed as 2 to keep the process inside bounder conditions.

As well as there is a rate of convergence to assure that the direction in correct way, But in this problem it can be achieved only for illustration, therefore

$S^4 = X^4 - X^1$

$S^4 = \frac{S^4}{//S^4//} = \frac{[0,0,1]}{///[0,0,1]//}$

The iteration can be terminated here because in step 4 the velocity is in a maximum rate 1.72 m/sec with laminar state which means that Reynolds number is in a minimum 2568.5 and less than 3000.

As (Ravindran,Ragsdell and Reklaitis, 2006) indicated that Powell's method can be explained in four stages as shown below.

First stage: Define X^0then initial point should be set then set of N linearly independent direction as S^i which i =1, 2, 3, …. N.

Second stage: Minimize N+1 direction by using earlier minimum to start next search then setting S^N to be first and last search.

Third stage: From new conjugate direction, Parallel subspace property should be used.

Fourth stage: Delete S^1 and it should be replaced by S^2 then new conjugate can be set in S^N and Going to stage two.

2- Discussion

2.1 Results and evaluation of Powell's conjugate method

As shown in table-5, the model of Venturi Blender with nominal design, the value of velocity should be less than 1.89 m/sec in order to make Reynolds number in laminar conditions and any value of velocity more than 1.89 would be affected the patient and efficiency of the model, also. Therefore Powell's conjugate method could be the best solution to enhance the performance of Venturi Blender. As illustrated in table--6, five iterations were applied on venture blender problem and it can be seen that how Powell's method has positive response to the problem. For example; it can be seen that from second iteration that Powell's conjugate method has reacted rapidly to give the results accurately. As Rao (1996) mentioned that Powell's conjugate direction method could be simple process because a previous search direction may use to start next direction, by this process, Powell's method may make the point to be converging in three iteration almost rather than take many times of steps. The application of Powell's conjugate direction method was achieved successfully and the result which have obtained applicable. Generally, Powell's conjugated may have significant role in industrial application. As well as this research giving vast view about using Powell's conjugate technique to solve this type of venturi Blender problem and illustrates the differences with other applications or example simplex Search method. Finally, industry is growth step by step which leads to increase applications over the world then complex problems will be generated. Therefore Powell's conjugate method needs to be updated every time to solve complicated problems in future. ANSYS simulation program has significant role during computation process and accuracy in values can be found in ANSYS program rather than regression equation. Therefore error in calculation was found between values in ANSYS program and nonlinear regression equation approximately between 1-10%

SN.	Diameter of the nozzle Inlet D1(mm)	diameter of the nozzle Outlet D2 (mm)	diameter of blender Outlet D3 (mm)	Reynolds number Less than	Velocity m/sec Less than
Nominal Design	5	1.5	22	2841	1.89

Table 5: Nominal design values

SN.	Diameter of the nozzle Inlet D1(mm)	diameter of the nozzle Outlet D2 (mm)	diameter of blender Outlet D3 (mm)	Reynolds number	Velocity m/sec
Optimised Design	3	1.5	26	1973	1.32
	3	1.69	26	1704.3	1.25
	8.45	1.69	26	2568	1.72
	8.45	1.79	26	2531.4	1.69
	8.54	1.79	28	2129.7	1.43

Table 6: results by using Powell's conjugate method

The idea of having results of optimum point is based on starting from low velocity and to attempt to obtain maximum velocity with least turbulence. Table-7 shows that first iteration can be started from 1.32m/sec with low Reynolds number 1973, it can be seen from next iteration that the velocity is going to be less than first iteration, the same with Reynolds number 1.25 m/sec, 1704.3 in series. While in third iteration, it could be seen that the velocity and Reynolds number were sharp increased 1.72 m/sec, 2568 sequentially compare to previous values. Again in fourth and fifth iteration, the values of velocities and Reynolds number are going to slight decline as shown in table-7. The quantity of lambda was gone to be large number which makes convergence could not be happened therefore it was assumed that to be 2, this type of error could be happened for some reasons for instance the regression equation may be a factor to obtain such error and other reasons. According to Rao (1996), he mentioned that minimizing iteration of lambda could be only approximate, therefore the direction may not be converging, and thus the problem may require more number of steps for carrying out the convergence.

Runs	factors													
	Coded values			Actual value									Response	
	X1	X2	X3	D1	D2	D3	X1^2	X2^2	X3^2	X1X2	X2X3	X1X3	Reynold No.	velocity
1	-1	-1	0	3	1.3	22	9	1.69	484	3.9	28.6	66	2392	1.6
2	-1	1	0	3	1.7	22	9	2.89	484	5.1	37.4	66	2213	1.4
3	1	-1	0	7	1.3	22	49	1.69	484	9.1	28.6	154	3379	2.26
4	1	1	0	7	1.7	22	49	2.89	484	11.9	37.4	154	2990	2
5	-1	0	-1	3	1.5	18	9	2.25	324	4.5	27	54	2198	1.47
6	-1	0	1	3	1.5	26	9	2.25	676	4.5	39	78	1973	1.32
7	1	0	-1	7	1.5	18	49	2.25	324	10.5	27	126	3408	2.28
8	1	0	1	7	1.5	26	49	2.25	676	10.5	39	182	2990	2
9	0	-1	-1	5	1.3	18	25	1.69	324	6.5	23.4	90	2317	1.55
10	0	-1	1	5	1.3	26	25	1.69	676	6.5	33.8	130	2870	1.92
11	0	1	-1	5	1.7	18	25	2.89	324	8.5	30.6	90	3827	2.56
12	0	1	1	5	1.7	26	25	2.89	676	8.5	44.2	130	2631	1.76
13	0	0	0	5	1.5	22	25	2.25	484	7.5	33	110	2841	1.89
14	0	0	0	5	1.5	22	25	2.25	484	7.5	33	110	2841	1.89
15	0	0	0	5	1.5	22	25	2.25	484	7.5	33	110	2841	1.89

Table 7: applying Box-Behnken Design method and shows minimum velocity

2.2 Comparison between Powell's conjugate direction Method and generic method (Simplex Search S^2 Method)

After applying Powell conjugate method on the venturi blender problem and to compare it with generic method, it can be seen that Powell conjugate method is more efficient and faster than simplex search method to reach the optimum point. As Atherton (2013) stated that Powell's conjugate method can be an active method and the method has positive response to converge rapidly. As well as Ravindran, Ragsdell and Reklaitis (2006) stated that one of Simplex Search Method's drawbacks is the process of getting minimum point is slow. As well as it may not use previous information to improve the action of problem such as, the store data in each iteration. It can be seen that Powell's method led to optimum point in four iterations regardless of initial point. The efficiency of method can be made the quadratic function to converge accurately in limited numbers of iterations without need to derive the function while a simplex search method needs more numbers of iterations to converge (Chapra and Canale, 2006). Three operations can be used in simplex method application in order to reach optimum point, reflection, contraction and expansion and in each process all the coordinates have same factor and different coefficient, therefor this may cause a problem during application particularly with several variables, and thus multiplier would be very large, hence this problem could be one of the disadvantages of simplex search method (Rao, 1996). In addition, the result which obtains from simplex method will be inaccurate as Bartholomew-Biggs (2008) stated that simplex Search method is very difficult and complex compare to other methods. In addition, inaccuracy can be another disadvantage for simplex method which affects by factor α for instance; if the magnitude of factor α was reduced, the search process generally should be continued with this error (Ravindran, Ragsdell and Reklaitis, 2006). Moreover, in Powell's method, there are two factors to select quadratic form. Firstly, it is nonlinear function to minimize. Secondly, all nonlinear may be approximated by quadratic in other word; the algorithm on quadratic would converge for general function. (Ravindran, Ragsdell and Reklaitis, 2006).

2.3 comparison between reference Model and optimised model

Table-8 clearly show that there is a difference between nominal dimensions and new design model and any changing in design factors would be influenced to properties of the system .For example the diameter of the nozzle at the inlet can be vital factor which effect on the quantity of Oxygen’s flow rate. As well as the inlet diameter being a factor which affect back pressure particularly when the back pressure is very high therefore the optimised design would improve the efficiency of the model. And, also the diameter in outlet of nozzle in nominal design may expose to turbulent conditions, while new design may avoid turbulence states at suitable velocity and Reynolds number as shown in figure 9. Similarly, for a new design of a diameter of blender at out let may influence on velocity and Reynolds number both. Generally, optimization shape any system can be an important factor to change of performance or efficiency of that model. As Mohammadi and Pironneau (2004) pointed out that shape optimization could be involved to sensitivity of flow rate in channels and improving the efficiency which involves the change of pressure between inlet and outlet of boundary condition.

SN.	Diameter of the nozzle Inlet D1(mm)	diameter of the nozzle Outlet D2 (mm)	diameter of blender Outlet D3 (mm)	Reynolds number	Velocity m/sec
Nominal Design	5	1.5	22	2841	1.89
Optimised Design	8.45	1.69	26	2568.5	1.72

Table 8: values of nominal and optimised design

Figures-3 and figure-4 are set only for illustration.

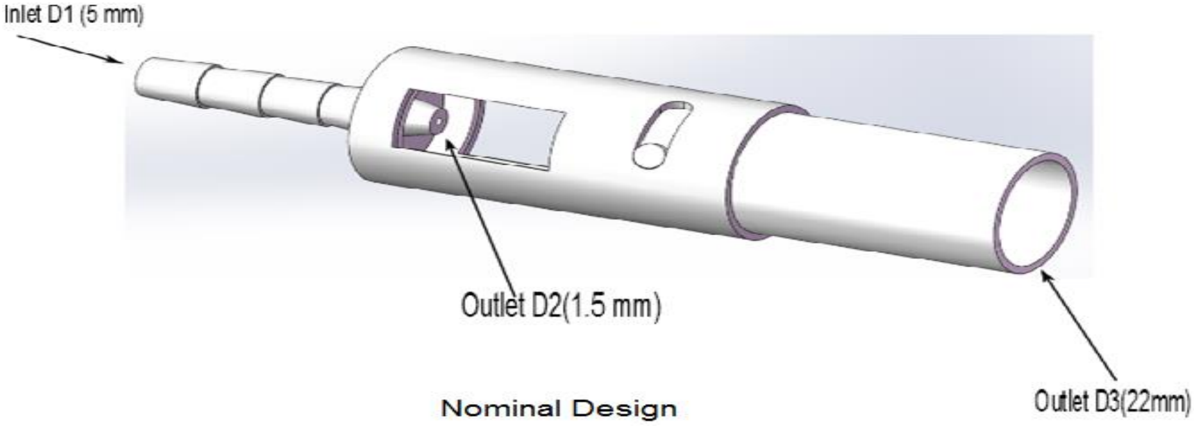

Figure 3: Nominal Design of venturi Blender

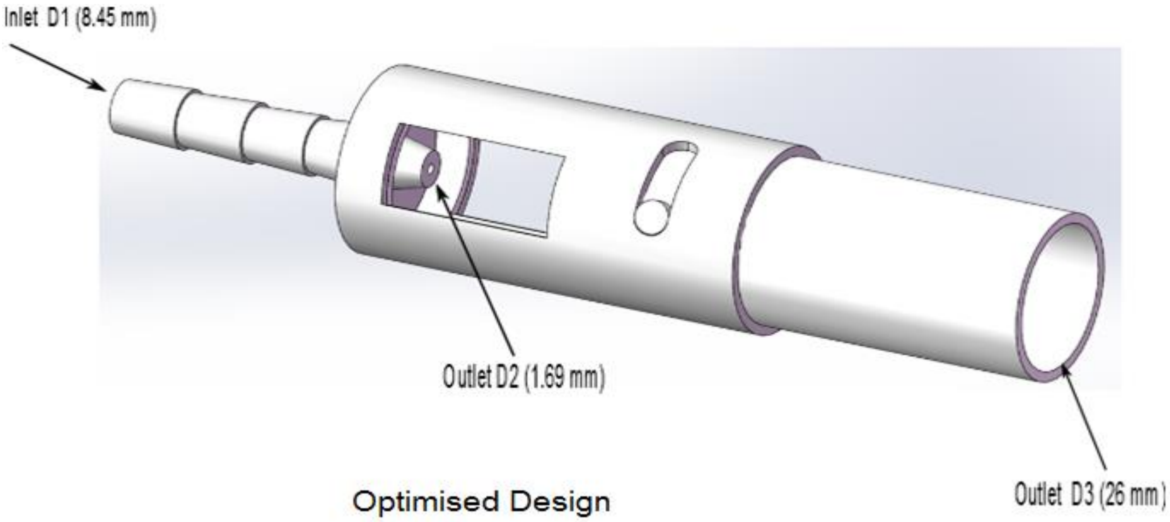

Figure 4: Optimised Design of Venturi Blender

References

Atherton, M. (2013) Pattern/Direct Search, ME5542. [Lecture notes] An optimization. Advanced Modelling and Design Module, Brunel University, Advanced Mechanical Engineering, Room 267, 21^{th} November 2013.

Bartholomew-Biggs, M. (2008) *Nonlinear optimization with engineering Application.* New York: Springer Science +Business Media, LLC

Chapra, S. and Canale, R. (2006) *Numerical method for engineering.* 5^{th} edn. New York: McGraw Hill Companies, Inc.

Kao, C., Li, C. and Chen, S. (2002) 'Simulation response optimization via direct conjugate direction method', Teaching in higher Education, pp. 541-552.

Mohammadi, B. and Pironneau, O. (2004) 'Shape optimization in Fluid Mechanics', Teaching in higher Education, pp. 255-79. doi: 10.1146/annurev.fluid.36.050802.121926

(Myers, R., Montgomery, D., and Anderson-cook, C. (2009) *Response surface methodology.* 3^{rd} edn. New Jersey: Wiley& Sons, Inc.

Rao, S. (1996) *Engineering Optimization*: Theory and Practice. 3^{rd} edn. New York: John Wiley & Sons, Inc.

Ravindran, A., Ragsdell, K. and Reklaitis, G. (2006) *Engineering Optimization*: Methods and applications. 2^{nd} edn. New York: John Wiley & Sons, Inc.