International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-4, November 2019

Optimization of Parameters to Improve Ventilationin Underground Mine Working using CFD

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***Abstract:**In underground mine, it is very important to maintain fresh and sufficient air in unventilatedareas to maintainsafeworkingenvironment for workers. To study the behaviour of airflowin underground mine, a T shaped crosscut region of Bordand Pillarmining is considered forsimulation in two differentcases: without and with thin brattice positioning at crosscutregion. Brattice is cost effectiveventilationcontrol device todeflectair into unventilatedareasin undergroundmine.Theultimate objectiveis to find the bestlocation anddimensionofbrattice across the crosscut region by which one can getmaximum velocity at dead end. Inthis thesis, a computationalfluiddynamics (CFD) and optimization algorithms areconsideredfor maximizing the air flow at the dead end byplacing a brattice at optimumlocation. Twodifferentoptimization algorithms: multi-objective genetic algorithm(MOGA)and non-linearprogramming ofquadraticLagrangian(NLPQL) optimization techniques were used in thisstudy.ANSYS FLUENT software is used forCFD modeling at T-shaped crosscut region andcomputes the simulation result ofair flow velocity at dead end. Optimization techniquesareusedfor tooptimize four input parameters; brattice position verticalandhorizontal from thewall of crosscut region and width andlength of brattice.The objectives for optimizations aretomaximize the velocity at dead end and minimize the pressuredrop in crosscut region.Comparisonis carried out betweencrosscut region without and with a thinbrattice usingoptimization techniques and found the best location anddimensionof brattice. To increasethe air flow velocity at dead endincrease the safe working for workers and supplyadequateair atworking face.*

***Keywords:** Optimization, Underground Mine, Underground Ventilation, CFD, Ansys FLUENT, MOGA*

I. INTRODUCTION

In underground mining, it is of particular importance to maintain fresh and cool air inunventilated areas to maintainsafe working environments for workers inside a coal mine.Theunderground mining environment is subjected to the dangers ofheating due to excess oxygenas well aspresenceof dangerous gases such as methane. As a result, air isinjected intounderground mines as a way toventilatethesurrounding air. This serves to dilute as well asreduce theair temperature in themine. By hanging assimple adevice as a brattice sail, as airis injected intoa mine, brattice sails can be aid the airflow intounventilatedareasand bringcontaminants out of the region.

Aminossadati and Hooman compared the different lengths of brattices and theireffectiveness withregardto theirlengthinto the crosscut region [1]. In their study,itisnoted thatwith brattices lengths up to entire lengthof thecrosscut region proved tobe most effective.However, the brattice lengths were only confined to asimple crosscutregion in their study.

Computational Fluid Dynamics (CFD) is the simulation of fluids engineering systems usingmodeling(mathematicalphysicalproblem formulation) and numerical methods(discretization methods, grid generations solvers, andnumericalparameters etc).To solvethe fluid problem, physical and chemical properties of fluid should be known.Then mathematicalequations areused to describe thesephysical properties. If the problemconsist the turbulentflow then there are few turbulent models thatarealso useduring CFDanalysis [2].

II. EXISTING RESEARCHES

Kurnia et al. developed a mathematical model for methane dispersion in anunderground mine tunnelwithdiscretemethane sources and various methods to handle it,utilizingthe CFD approach[3]. The study provided some new ideasfordesigning an‘‘intelligent’’ underground mineventilation system whichcan cost-effectivelymaintainmethaneconcentration below the critical value.

Chanteloup and Mirade reported the implementation of the ‘‘age of air’’ concept intocommercial CFD codeFluentthrough user define function (UDF) to assessventilationefficiency inside forcedventilation food plantsusing twotransientmethods and the steadystate method.The resultsindicatedthat calculating local mean age of air(MAA) bysteadystate method proved the best compromisebetweenaccuracy of results and computation time[4]. Rajaket. al. presented a study of dust behavior intwo auxiliary ventilation systemsby CFD models,takingintoaccount the influence of time [5]. The accuracy of thesemodels wasassessed and validated by measurement ofairflow velocityand respirable dust concentrationtakenin six points of six roadways in an operating coal mine. It was concluded, that thepredictive models allowedmodification of auxiliary ventilation and improved healthconditions and productivity.

Manuscript published on November 30, 2019.
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calculated the losses in 138 situationsofcircular tunnels, varying tunneldiameter, air velocityandsurfacecharacteristics, by both traditional andCFDmeans.Thereresults of both methods were compared andadequatecorrelation wasobserved with CFDvaluesconstantat 17% below the values calculated by traditional means[6.

Xu et al. conducted a laboratory experiment usingtracergas methodology inconjunction with CFD studiestoexaminethe ventilation status of a mine after anincident [7]. Alaboratory model mine was built based on aconceptual mine layout whichallowed changesto theventilation status to simulate different ventilation scenarios after an incident.

Sasmito et al. carried out a computational study toinvestigate flow behavior in a‘‘room and pillar’’undergroundcoalmine [8]. Several turbulence models, SpallartAlmaras,kEpsilon, k Omega and Reynolds Stress Model,werecompared withtheexperimental datafrom Parraet al.(2006). The Spallart–Almaras model was found to besufficientforpredictionof flowbehavior adequatelyin underground environment whilst keeping lowcompu-tational cost.

A studycarried out in a deep underground mine located inNorthern Spain,by measurementsofblastinggases, COand NO2, in three crosssections of thecoal headinglocatedat 20, 30 and 40 m from the headingface [9].Mathematicalmodels of gas dilution weredeveloped accordingto thedilution time after blasting. Theobtained values by theexperimentalmodels and thevalues of other mathematicalmodels showed differences, whichindicated the needtoobtain in eachunderground work its own dilutionmodelsof blastinggases.

Ren et al. (2014) conducted a study to investigate bothairflow and respirable dispersionpatterns over the bin andalong thebeltroadway to design a better dust mitigationsystem.The results showed the dispersion of airborne dustparticles from theunderground bindictated by theventilation airflow pattern distributed widely in the beltroadway and atvarious elevationsabove the floor,contributing to high dust contamination of intake air. CFDmodeling results showed that ventilation from thehorizontalintake at a rate of 10–13 m3/swould help diluteandconfine the majority of dust particles below theworkers’normal 9 breathing zone. An innovative dustmitigationsystem based on the water mist technology wasalsoproposed.Thefeasibility of the new system on respirabledust control was investigatedand verified from atheoretical perspective followedby a detailed design,which wasapproved for field implementation.

III. METHODOLOGY

A. Problem Identification

Define goals-
In this section, the goals according to theproblem are identified. Theultimate objective is togetmaximumvelocity atthedead end and minimizethe pressure dropacross thecrosscut region.

Identify domain: In this section, we identify the domainofour problem. In Tshaped crosscut region, we identifydifferrentdomainlike inlet, outlet, dead end or workingface, brattice etc.

B. Pre-Processing:

In Pre-processing section, the geometry of the undergroundmineventilation cross-cut isdeveloped using ANSYSdesignmodule. The domain is discretized or meshed intomany finite domains by mesh module. After the meshing,the mine ventilation system is simulatedby FLUENTsolver. The solver parameters are set according to fluid model, material,properties, boundary conditions, solvingtechniques, turbulence model, convergence criterion etc.Foroptimization purpose,the objective is maximized i.e.the velocity at dead end andpressure drop is minimizedwithin the constrained bound. Tocalculate the objectivefunctionalues within the constrained domain,FLUENTsolver is called for simulating those values.

Geometry (Model Development):3D models of T-shapedcrosscut region without brattice and with brattice are prepared andpresented in Figure 1 and Figure 2respectively. Thegeometry is created to reflect theactual underground minecross-cut.

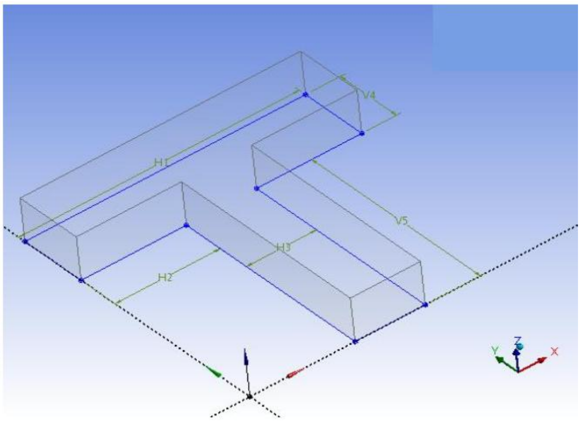

Fig. 1. T-Shaped crosscut region without brattice (3D view)

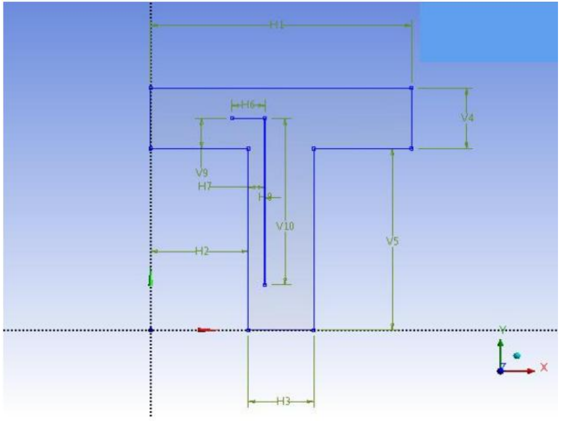

Fig. 2. T-Shaped crosscut region with brattice (2D view)

The dimension of crosscut region and ventilation isfollowing in Table 3.1. For normal case,it was considered that the bratticewidth, brattice length, brattice positionvertical, and bratticeposition horizontal are known.However, during optimization,those values are selected tomaximize the velocity at the dead end.

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Table- I: Dimension of Geometry parts

Geometry Parameter	Name	Value (Meter)
H1	T-Section width	16m
H2	Crosscut region distance	6m
H3	Crosscut width	4m
V4	T-section Length	4m
V5	Crosscut Length	12m
H6	Brattice width	2m
V10	Brattice length	11m
V9	Brattice position vertical	2m
H7	Brattice position horizontal	1m

Mesh: In mesh section, geometry is imported into theANSYS mesh module and performs a fine meshing size to both thegeometries of T-shaped withno bratticeand withbrattice as shownFigure 3 and Figure 4, respectively

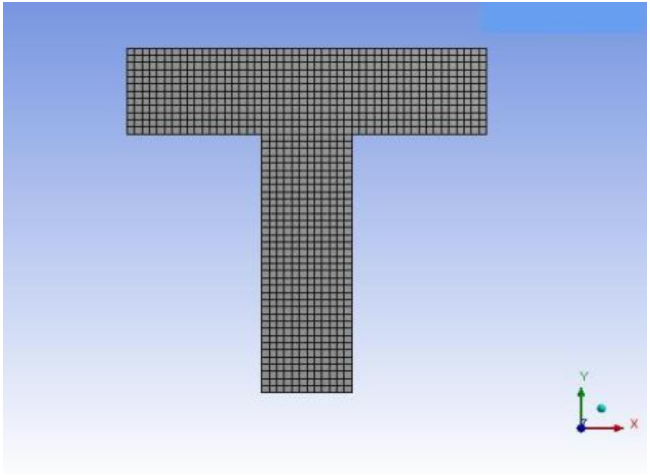

Fig. 3. Meshed Crosscut region with no brattice

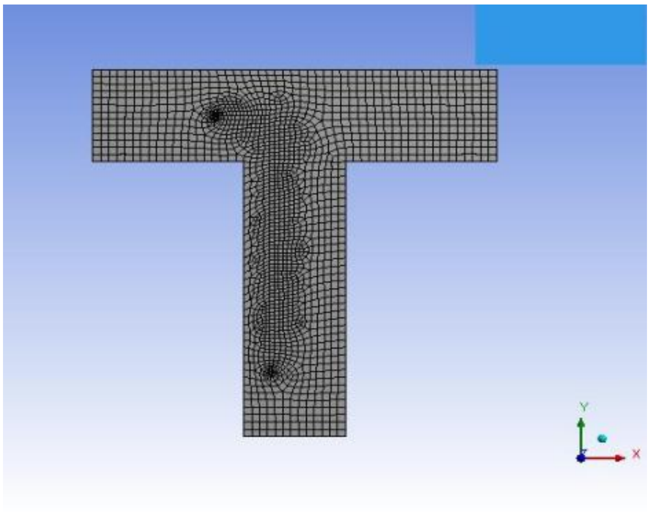

Fig. 4. Meshed Crosscut region with brattice

C. Objectives and Optimization Methods

If the location of the brattice is known i.e. the values of H6, H7, V9, and V10, one cancalculate the values of *Vd* and *Pd* usingthe CFD analysis. According to resulted valueofoutput parameters from CFD analysis, the optimizationtechniques in GoalDrivenOptimization in ANSYSsoftware can be applied to select the values of H6, H7, V9, and V10.

Optimization techniques can be used for designoptimization in three ways: the Screeningapproach, the MOGAapproach, orthe NLPQL approach. The Screening approach isa noniterative direct sampling method by a QuasiRandomnumber generatorbased on theHammersley algorithm.The MOGA approach is an iterative MultiObjectiveGeneticAlgorithm, which canoptimizeproblemswithcontinuous input parameters. NLPQL is agradient basedsingle objective optimizer which is based on Quasi-Newton methods. Usuallythe Screening approach is used forpreliminary design, which may lead to apply the MOGAor NLPQLapproaches for more refined optimization results.

Non-Linear Programming by Quadratic Lagrangian(NLPQL) approach:

NLPQL requires that a goal isdefined for atexactlyone output parameter. Only a singleoutput goal is allowed. In NLPQL approach, optimizationdomain shownbyTable 3.5and optimizationobjective for this approach is shown by Table II. NLPQLapproach is oneobjective orientedalgorithm.

Table- II: Optimization Objective for NLPQL approach

Output Parametrs	**Net Pressure (Pd)**
Optimization objective	**Minimize**

Figure 5 is prepared by NLPQL optimization theory. Asample set of 100 samples pointwhich is relation betweentheoutputparameters i.e. velocity and pressure fromCFDanalysis

.The results from NLPQL demonstrated that, sameas MOG Aalgorit-m, the velocity at thedead end increaseswith increasing the pressure difference. Other way, it canbe conclude thatto get moreair, one has to crease morepressure difference between two points.

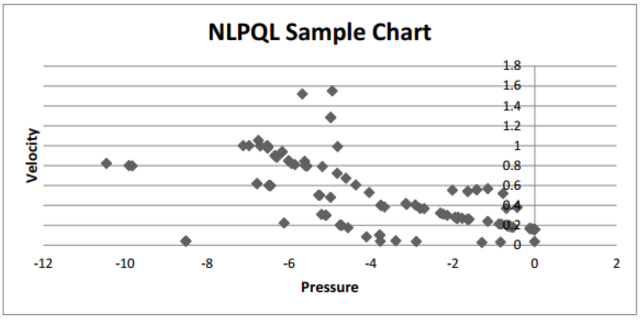

Fig. 5. Sample chart prepared by NLPQL optimization technique

IV. RESULT ANDDISCUSSION

A. Simulation Results

Case (1): With no brattice

As shown in Figure 6, the velocity at dead end is much less because high quanity of airpasses to the outletsectionbec-ausethere is no obstacle on the way of air flow and airflows straight from inlet to outlet. Velocity varies near thecorners ofcrosscut region, it is due tosudden change ingeometry of c rosscut region.

Air flows from high pressure to low pressure, so pressureat inlet section is more than theoutlet section as shown inFigur e7. Pressure also varies at corners due to suddenchange inge ometry. There is also reversible flow occurs.

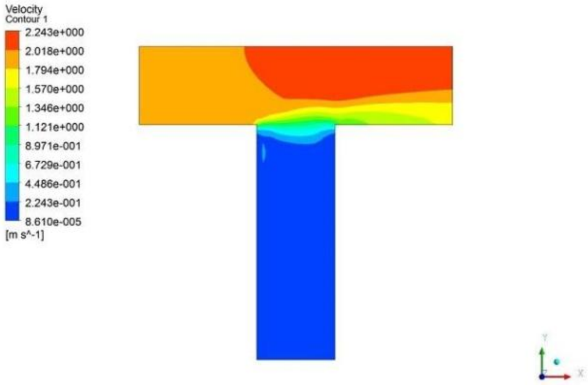

Fig. 6. Velocity contour of T-shaped Crosscut region without brattice

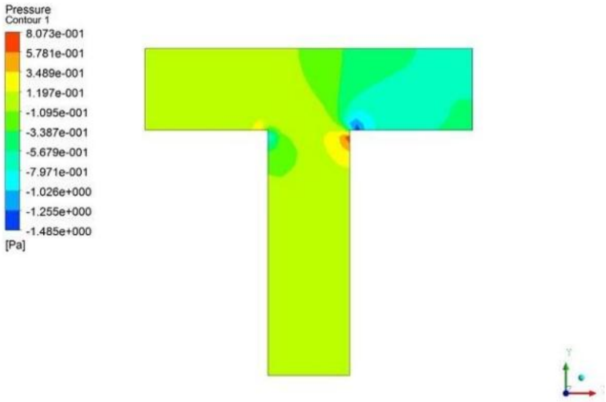

Fig. 7. Pressure contour of T-shaped Crosscut region without brattice

The results demonstrated that the air velocity at the deadend or working face is 0.00035 m/s andpressure incross-cut region is-0.1375 Pa.Table III shows the result incaseof crosscut regio nwith no brattice.

Table- III: Final result in case of crosscut region with no brattice

	Velocity at dead end (Vd)	Pressure drop (Pd)
	0.00035 m/s	-0.1375 Pa

Case (2): With thin brattice

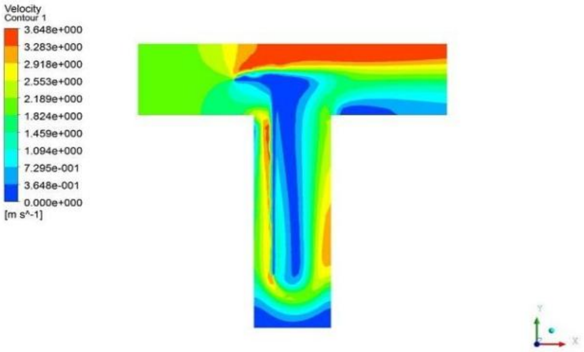

Fig. 8. Velocity contour of T-shaped Crosscut region with thin brattice

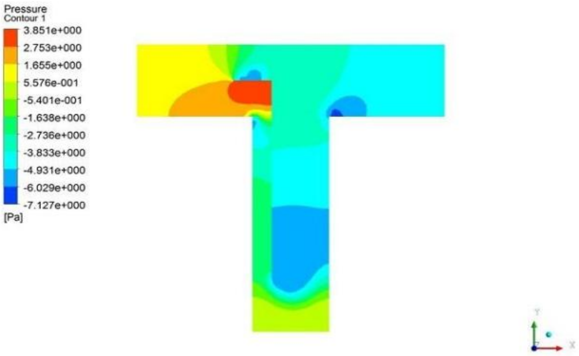

Fig. 9. Velocity contour of T-shaped Crosscut region with thin brattice

Case (3): With thin brattice by MOGA optimization

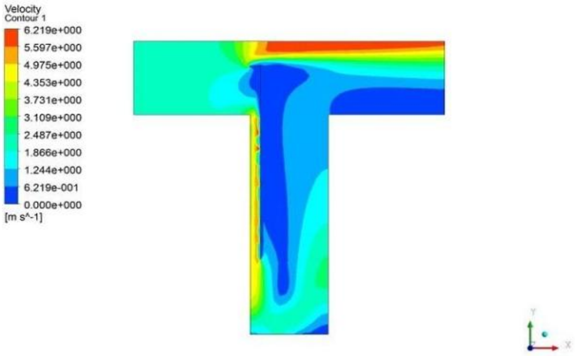

Fig. 10. Velocity contour of T-shaped Crosscut region with thin brattice by MOGA optimization

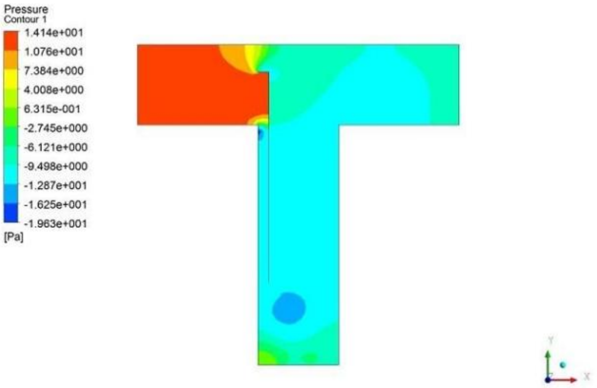

Fig. 11. Pressure contour of T-shaped Crosscut region with thin brattice by MOGA optimization

Case (4): With thin brattice by NLPQL optimization

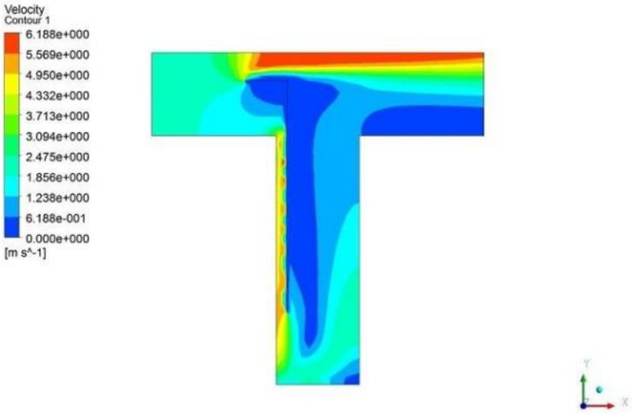

Fig. 12.Velocity contour of T-shaped Crosscut region with thin brattice by NLPQL optimization

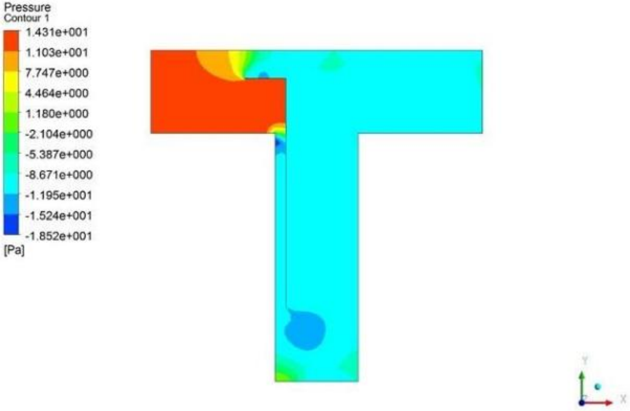

Fig. 13. Velocity contour of T-shaped Crosscut region with thin brattice by NLPQL optimization

B. Correlation between Input Parameters and Velocity

Brattice position vertical v/s Velocity: Figure 14 shows that as increasing the vertical bratticeposition, velocityatdeadendor working face also increases.As increasing the vertical position, quantity of air increasesthrough the bratticewall and highvelocity reaches atdeadend because air quantity reaches at outlet is less and vice-versa.

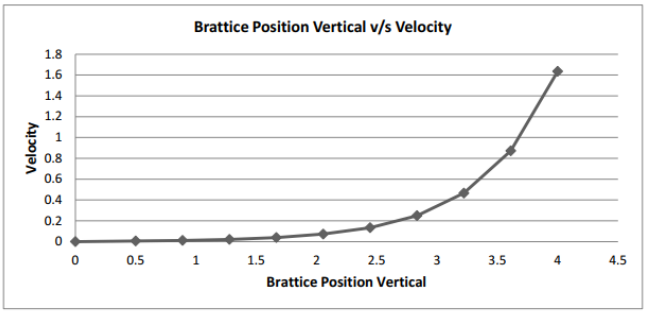

Fig. 14 Relation between brattice position vertical and velocity

Brattice position horizontal v/s Velocity:Figure 15shows that as increasing the horizontal bratticeposition,velocity atdead end orworking facedecreasesexcept at very initial. At zero dimension of horizontalbratticeposition, velocity at deadend also is same as thevelocity that in case of no brattice becausethere is no waytoreach air at dead end. After increasinghorizontal positionof brattice fromzero, velocity at dead end increases rapidlybecause high velocity reaches at dead endthroughthebrattice wall. As increasing the horizontal position, distance between brattice andairhit position onbratticeincreases so the quantity of air decreases through the bratticewall andreaches less air quantity.

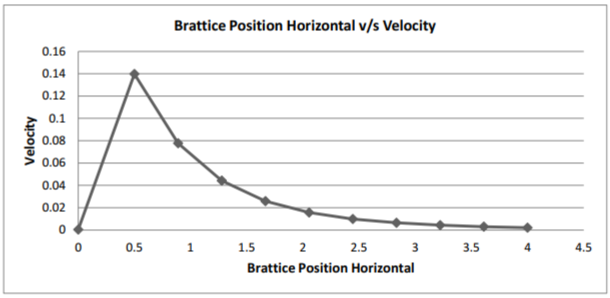

Fig. 15. Relation between brattice position horizontal and velocity

Brattice width v/s Velocity: Figure16 shows that as increasing the brattice width, velocity at dead end workingface remains same. There is no effect of brattice width on

velocity at dead end.There is no pointto hit velocityonbrattice widthbecause it is horizontal with respect to theair flow so will beno effect on air quantity at dead end and remains same as thecase of brattice.

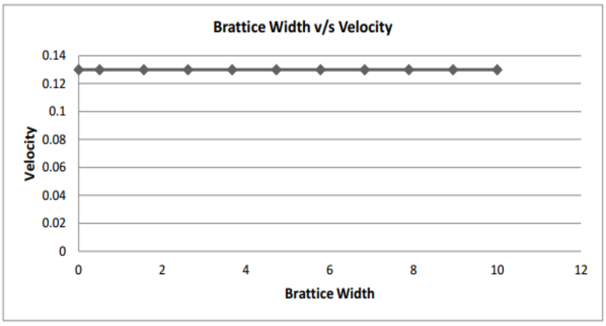

Fig. 16. Relation between brattice width and velocity

Brattice length v/s Velocity: Figure 17 shows that asincreasing the brattice length, velocity at dead end workingfacealso increases. The lower portion of brattice isnearthe dead end so as increasing the length,air quantity wouldbe increasesthrough the brattice wall at dead end andifbrattice lengthdecreases then quantity of air wouldbe lessat dead end.

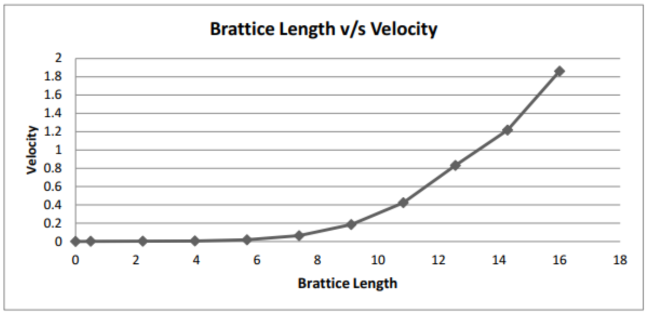

Fig. 17. Relation between brattice length and velocity

V. CONCLUSION

A computational fluid dynamic study is conceded toachieve maximum velocity at dead endor working face in a T-shapedcrosscut region. Spalart-Allmaras turbulent model isused forCFD analysis. There are two optimization techniquesareusedto optimize the parameters toachieve bestresult. In this experiment, a thin brattice is the most effectve for simulating thevelocity at dead zone inside thecross-cut region. A thin brattice is also more space efficient.Anaddition of a thin brattice helpsin diverting the air flowin crosscut region. The optimizedresult of air flow at deadend in crosscut region is 65 75% of theoriginal case ofno brattice.The optimized result of input parametersi.e. location and dimension of brattice aid tomaximize theair flow velocity at dead end and minimize the pressureinside the crosscutregion. It is found that between the two optimization techniques, the result that is velocity atdeadendand keep pressure is minimized in T-shaped crosscutregionby NLPQLoptimization approach is better than theMOGA optimization approach.

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Retrieval Number: D8968118419/2019©BEIESP
DOI:10.35940/ijrte.D8968.118419
Journal Website: www.ijrte.org