Mining Science, vol. 23, 2016, 161−172

www.miningscience.pwr.edu.pl

Mining Science
(previously Prace Naukowe Instytutu Gornictwa
Politechniki Wroclawskiej, ISSN 0370-0798 in Polish)

ISSN 2300-9586
previously 0370-0798

Received: August 21, 2016; reviewed; accepted September 16, 2016

CFD SIMULATION OF THE BRATTICE BARRIER METHOD FOR APPROACHING UNDERGROUND MINE FIRES

Vancho ADJISKI[*], Dejan MIRAKOVSKI
Zoran DESPODOV, Stojance MIJALKOVSKI

Faculty of Natural and Technical Sciences, Mining Engineering, “Goce Delchev” University,
P.O. Box 201, 2000 Shtip, Macedonia

Abstract: Fires are the most feared hazard in underground mines. The problems associated with underground mine fires calls for special techniques and treatments in its prevention and fire fighting. Each mine fire presents unique conditions from the perspective of dealing with it. The purpose of this paper is to present Computational Fluid Dynamics (CFD) simulated fire scenarios on which is tested the brattice barrier method for approaching underground mine fires. With this experimental CFD model we can determine the effectiveness of this method. These simulations were performed to determine if we increase the air velocity into the roof with help of brattice barrier, will this remove the smoke and heat upstream of the fire so that firefighters can approach safely and extinguish the fire. We can also observe the explosive range of the particles and gases that travel upstream of the fire and are then forced back into the fire area by this brattice barrier method.

Keywords*: underground mines, fire scenarios, modelling fires, brattice barrier, approaching fires*

INTRODUCTION

Special conditions that are peculiar to underground mining, differentiate it from normal surface fire fighting operations. Because of this special conditions, new innovations are required to deal with cases of underground mine fires which is unique in itself. Some of the common hazards which should be taken into account in planning and approaching the fire fighting operation for mines, are list below (Banerjee, 2001):

- Gas hazards associated with the spread and generation of fires combustion products.

---

[*] Corresponding author: adziski.v@gmail.com (V. Adjiski)

doi: 10.5277/ msc162313

- Flashover phenomenon due to confined space fires.
- Smoke rollback effect.
- Fires affect on the underground mine ventilation.
- Inaccessibility to the fire.
- Other associated hazards and risks caused from the fires.

Effective strategies in fire fighting process that include optimal ventilation practices and procedures for combating underground mine fires would reduce severity of the mine fires. The decision to change the air velocity over a fire must be considered carefully. There are advantages and disadvantages to increasing, maintaining or reducing the air velocity over a fire and all of these must be considered carefully (Conti et al., 2005).

Reducing the airflow over the fire is done to limit the oxygen supply to the fire and slow the growth of the fire. The reduction of airflow to the fire may cause smoke and heat to rollback upstream of the fire and limit the firefighters approach to be able to effectively extinguish the fire (Ryan, 1996). Depending on the size and location of the fire, the heat and smoke may rollback and contaminate additional areas of the mine. The raise in the temperature can cause increased fatigue or heat exhaustion of personnel fighting the fire. Approaching and fighting underground mine fires can be impossible if high temperatures are present and may also damage roof supports and cause rock falls (cave-in).

Increasing the air velocity over a developed fire can have serious consequences that need to be recognised. If the air velocity is increased over a fire, unburned combustible products (particles and gases) that may have travelled upstream of the fire will be forced back into the fire (Klote, 2002). If these gases are in the explosive range, they could be ignited by the fire and cause an explosion. Increasing the air velocity may also increase the burning rate and rate of heat released from the fire. Sometimes, increasing the air velocity is the only way smoke and heat can be removed from the upstream of fire area so that firefighters can approach and extinguish the fire safely. Increasing the air velocity will lower the temperature upstream of the fire area, however, it may raise the temperature downstream from the fire (McPherson, 1993).

METHODS

SMOKE ROLLBACK EFFECT

It can be observed from both laboratory studies and field investigations that hot smoke and combustion products from a fire in a mine roadway may travel back a considerable distance against the direction of the primary ventilation flow, depending on how strong the fire is and the gradient of the mine roadway (Edwards et al., 2006). A declining mine roadway assists in the smoke rollback effect where incline gradient impedes the rollback effect. The above phenomenon is a result of a convection current rising from the fire and is known as the smoke rollback effect.

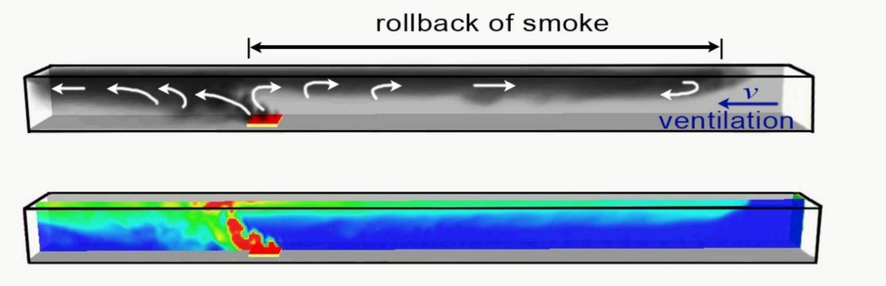

Fig. 1. Smoke rollback effect

When the convection current rising up from the fire, encounters lower ventilation air speed near the roof, they can overcome the lower air velocity and a counter current is set up. This air stream moves back upstream of the fire till its buoyancy is reduced by heat loss to the strata/roof and the air beneath. The cool tongue of the smoke lowers down and returns back with the ventilating air stream to the base of the fire, and thicken the smoke due to turbulent mixing (Edwards & Hwang, 1999). The hazards associated with the rollback of smoke are (Adjiski, 2014):

- Transportation of heat from the fire to the roof and at times causing rock falls due to heating of the rock surface and burning of timber supports.
- Allowing the flammable gases to reach the base of fire which can increase the risk of explosion.
- The rollback effect on a decline or hoizontal roadway creates resistance (from smoke, heat) in the top of the roadway above the fire thus increasing air velocity at the base of the roadway fanning the fire.
- The effects of smoke rollback can be a dangerous and potentially fatal threat to miners, firefighters and mine rescue teams, preventing them approaching close enough to be able to effectively extinguish the fire. This fire effect can occur directly over the heads of the firefighters and miners, enveloping them with hot fire gases, that can have fatal consequences.

The principle for dealing with the above hazards is to increase air ventilation speed in the mine roadway by restricting the opening with a brattice barrier which has width as the mining roadway and at least 60-70% of the mining roadway height (Mitchell, 1996). These measures would deflect all the ventilating air into the roof zone, and by mixing with the combustion products in the smoke stream would cool the air and disperse the smoke and gasses. It has been reported that the brattice barrier method has made it possible to approach a roadway fire in U.K. within 5 metres of its source (Eisner & Smith, 1954).

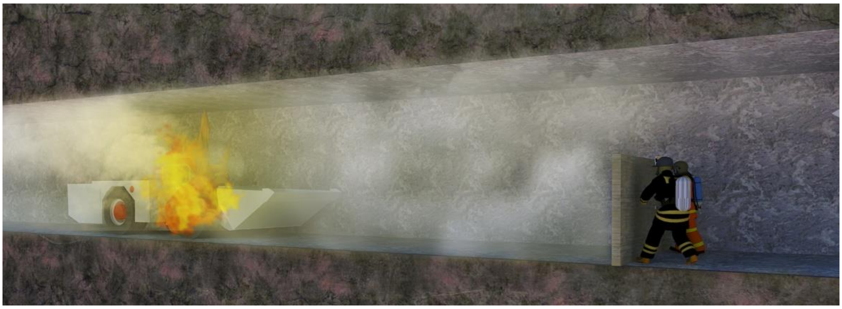

Fig. 2. Brattice barrier method for approaching underground mine fires

One of the method for analysing the brattice barrier approach of underground mine fires is to use CFD (Computational Fluid Dynamics) analysis. It should be noted that the CFD analysis can only be used to represent a small section of the mine ventilation network because of the large number of calculations performed in the analysis process and the current limitations of normal computer processing power.

MODELING OF FIRE SCENARIOS

For the purposes of this research paper, we have used the PyroSim software from the company "Thunderhead Engineering". PyroSim is a graphical user interface for the "Fire Dynamics Simulator" (FDS) (PyroSim User Manual, 2012). FDS models can predict smoke, temperature, carbon monoxide, and other substances released during fires. The results of these simulations have been used to ensure the safety in buildings before construction, evaluating safety options, reconstructing fires for post-fire investigation and assisting in firefighter training. The software solves numerically a large eddy simulation form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow, with an emphasis on smoke and heat transport from fires. This approach is very flexible and can predict and simulate different fire scenarios, including the ventilation in the same process (Adjiski et al., 2015).

Fire models describe the fire characteristics, for example (Hansen, 2010): heat release rate, burning rate of material, heat flow, smoke, generation of toxic gases, etc. In this paper we will model fire scenarios in which we will assume a fire caused by the ignition of the front right tire of a loader Scooptram ST 3.5. For the purposes of this research paper, in software PyroSim a 3D underground mining horizontal drift is modeled with the following dimensions: 4 m width, 3 m high, and 75 m long, in which is simulated fire of the front right tire of loader Scooptram ST 3.5. The cause of the fire ignition will not be analyzed in this paper. In large eddy simulations (LES), the grid size is an important factor to be considered. A smaller gird size the more detailed the information of the turbulent flow but this also needs more computation resources and a longer computing time. For this simulation, we take into account a moderate cell size (dx) of 0.12 m (Fig. 3). The mesh line for FDS is as follows:

- Actual (dx) size is 0.12(x), 0.12(y) 0.12(z), m.
- Distances are 75(x), 4(y), 3(z), m.
- Total number of cells are 460 800.

Tab. 1. Chemical and physical characteristics of the tire

Tire Size	Tire 17.50×25, 20 ply, L-5S,
Weight of a tire	248 kg
Density of tire	1150 kg/m^3
Simplified chemical hydrocarbon formula of tire	C_4H_6
Heat of combustion	44004 kJ/kg
Burning rate of tire (experimental data) (Totten et al., 2003)	0.062 kg/m^2.s

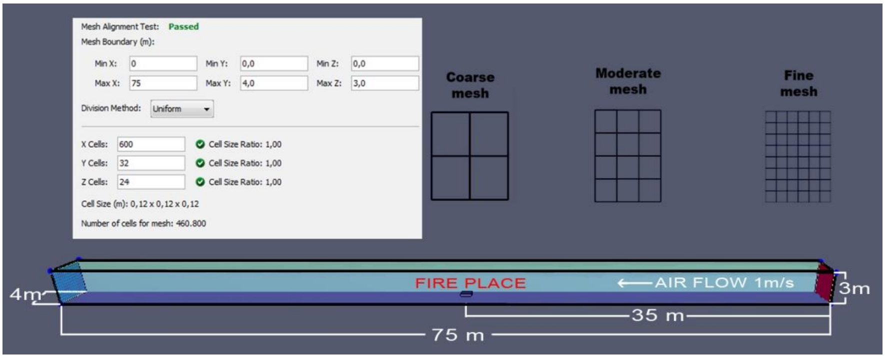
Mesh Alignment Test: Passed
Mesh Boundary (m):
Min X: 0 Min Y: 0,0 Min Z: 0,0
Max X: 75 Max Y: 4,0 Max Z: 3,0
Division Method: Uniform
X Cells: 600 Cell Size Ratio: 1,00
Y Cells: 32 Cell Size Ratio: 1,00
Z Cells: 24 Cell Size Ratio: 1,00
Cell Size (m): 0,12 x 0,12 x 0,12
Number of cells for mesh: 460.800

Fig. 3. Process of modeling moderate mesh in computer program PyroSim

Tab. 2. Lower and upper explosive or flammable limits of gases and vapours in air at ordinary temperature and pressure (Zalosh, 2003)

Gas	Lower Explosive or Flammable Limit (LEL/LFL) (% by volume of air)	"Upper Explosive or Flammable Limit (UEL/UFL) (% by volume of air)	Autoignition temperature
Carbon monoxide, CO	12	75	609 °C
Acetylene, C_2H_2	2.5	100	305 °C
Ethane, C_2H_6	3	12–12.4	515 °C
Ethylene, C_2H_4	2.7	36	490 °C
Hydrogen, H_2	4	75	500–571 °C
Hydrogen Sulfide, H_2S	4.3	46	232 °C
Methane, CH_4	5.0	15	580 °C
Ammonia, NH_3	15	28	651 °C

RESULTS AND DISCUSSION

CFD SIMULATION OF THE BRATTICE BARRIER METHOD FOR APPROACHING UNDERGROUND MINE FIRES

On the same 3D horizontal mining drift, we will perform two simulations, one of which will be without and one with the brattice barrier method. After the simulations we will analyse the results.

The airflow in the 3D horizontal mining drift is set to 1 m/s in both simulations. Measurements for average gas concentrations and temperatures were taken at locations downstream and upstream from the fire along the length of the 3D horizontal mining drift. The measurements and data were collected over the entire length of the fire scenario until the tire was consumed by the fire.

SCENARIO 1:

In scenario 1, we will perform CFD simulation of the fire scenario where we will not use the brattice barrier method for approaching the fire. From the software for modelling fires Pyrosim (PyroSim User Manual, 2012), and the chemical and physical characteristics of the tire (Tab. 1), we get the following experimental software results for Scenario 1, for simulated fire of the front right tire of loader Scooptram ST 3.5.

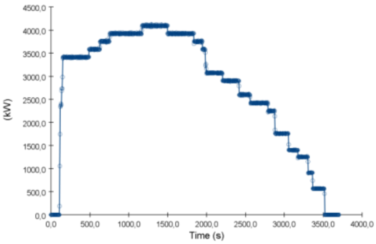

Fig. 4. Heat release rate of the fire

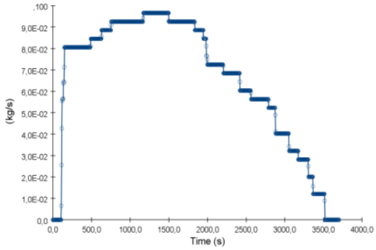

Fig. 5. Burning rate of the fire

Experimental software results for Scenario 1, downstream of the fire:

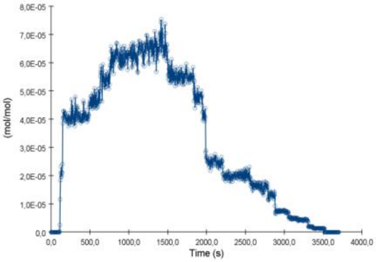

Fig. 6. CO concentration downstream from fire

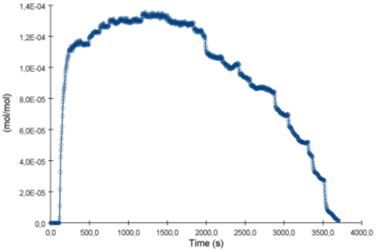

Fig. 7. SOOT concentration downstream from fire

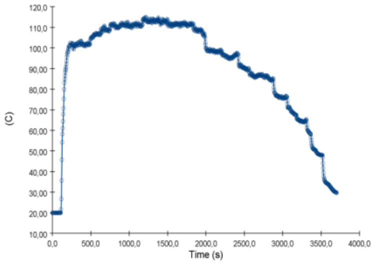

Fig. 8. Temperature downstream from fire

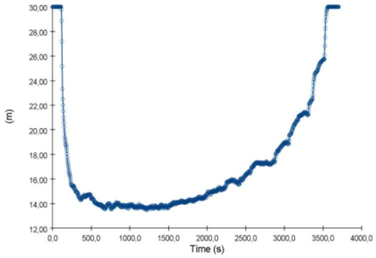

Fig. 9. Visibility downstream from fire

Experimental software results for Scenario 1, upstream of the fire:

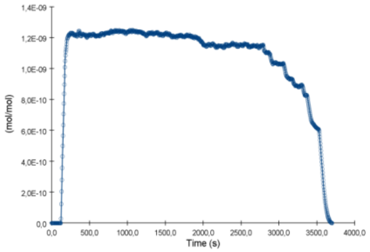

Fig. 10. CO concentration upstream from fire

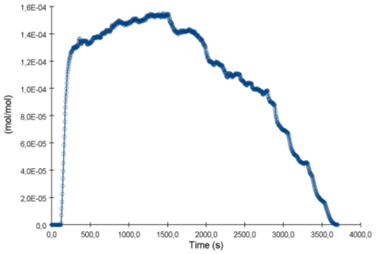

Fig. 11. SOOT concentration upstream from fire

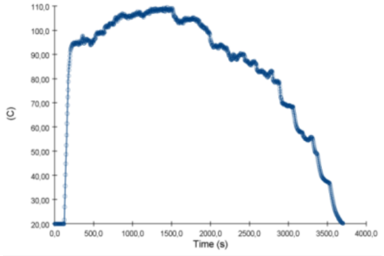

Fig. 12. Temperature upstream from fire

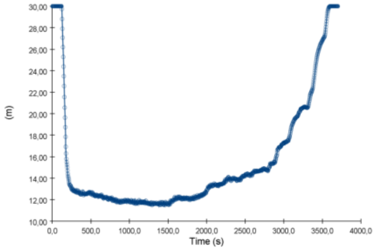

Fig. 13. Visibility upstream from fire

Fig. 14. CFD simulation of fire scenario 1, in computer program PyroSim

SCENARIO 2:

In scenario 2, we will perform CFD simulation of the fire where we will install the brattice barrier method 8 m upstream of the fire, 10 min after fire ignition. We will assume that 8 m is the optimal and safe distance for extinguishing the fire, and 10 min is the time needed for response and installation of the brattice barrier method. From the software for modelling fires Pyrosim (PyroSim User Manual, 2012), and the chemical and physical characteristics of the tire (Tab.1), we get the following experimental software results for Scenario 2, for simulated fire caused by ignition of the front right tire of loader Scooptram ST 3.5.

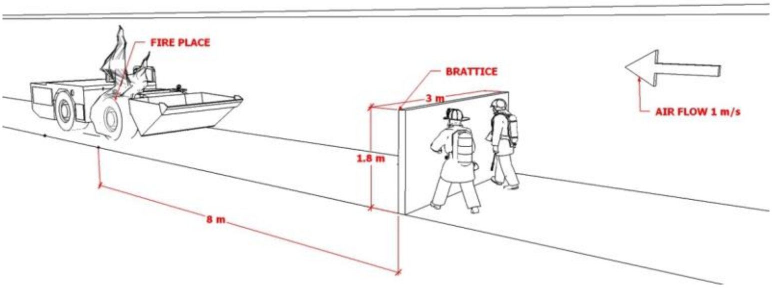

Fig. 15. Scene setup for scenario 2

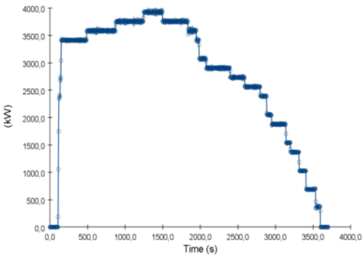

Fig. 16. Heat release rate of the fire

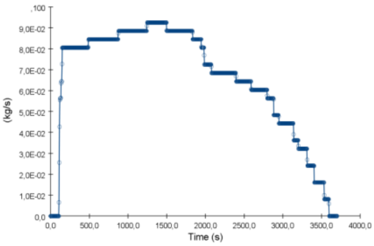

Fig. 17. Burning rate of the tire

Experimental software results for Scenario 2, downstream of the fire:

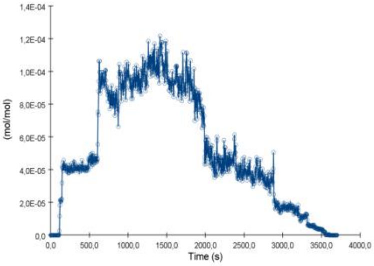

Fig. 18. CO concentration downstream from fire

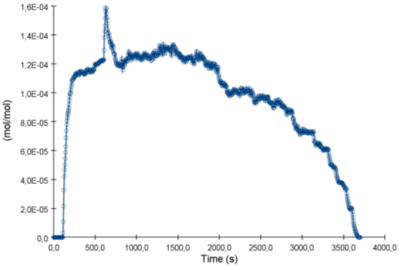

Fig. 19. SOOT concentration downstream from fire

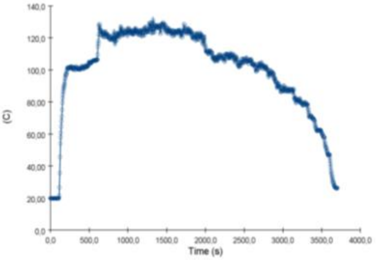

Fig. 20. Temperature downstream from fire

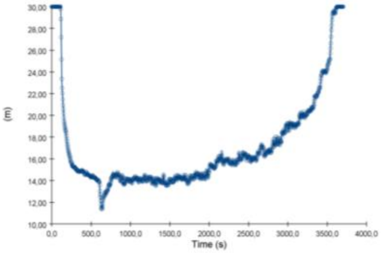

Fig. 21. Visibility downstream from fire

Experimental software results for Scenario 2, upstream of the fire:

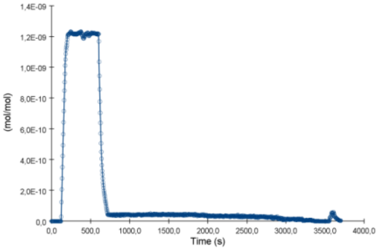

Fig. 22. CO concentration upstream from fire

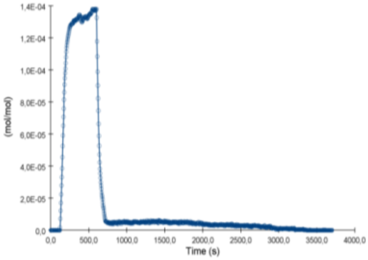

Fig. 23. SOOT concentration upstream from fire

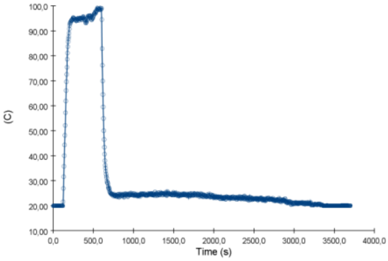

Fig. 24. Temperature upstream from fire

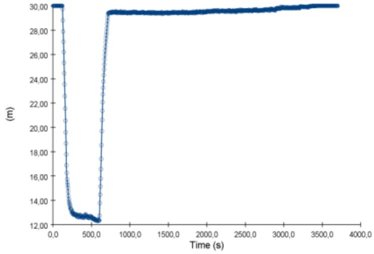

Fig. 25. Visibility upstream from fire

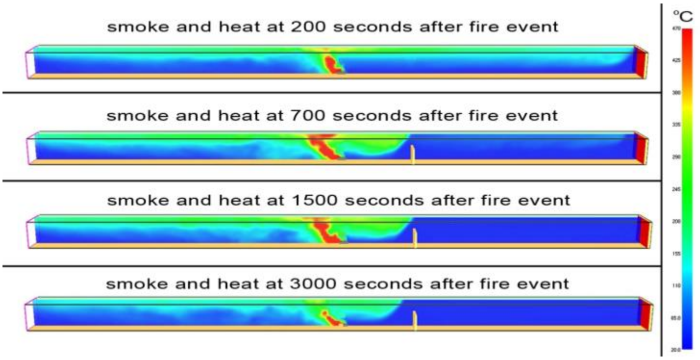

Fig. 26. CFD simulation of fire scenario 2, in computer program PyroSim

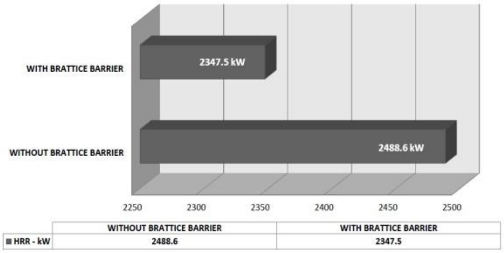

Fig. 27. Heat release rate of the fire

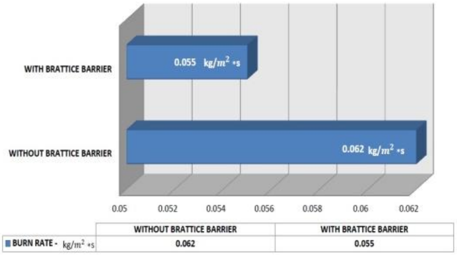

Fig. 28. Burn rate of tire

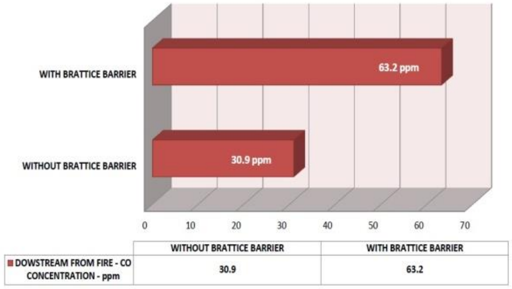

Fig. 29. Downstream from fire - CO concentration

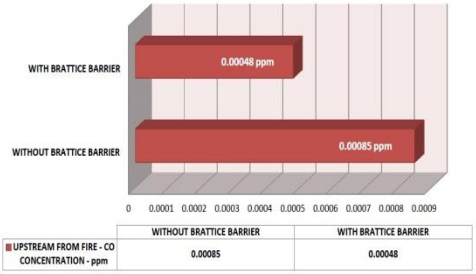

Fig. 30. Upstream from fire - CO concentration

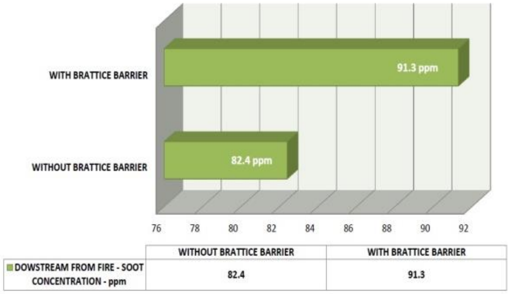

Fig. 31. Downstream from fire - SOOT concentration

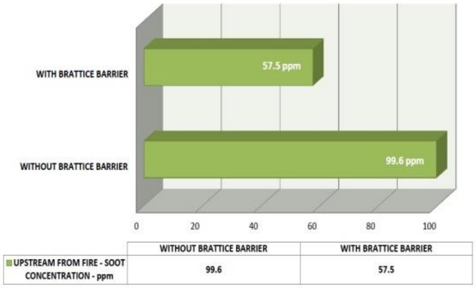

Fig. 32. Upstream from fire -SOOT concentration

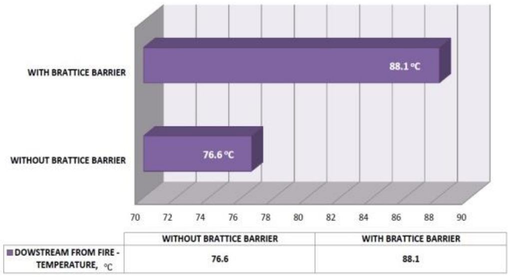

Fig. 33. Downstream from fire – Temperature

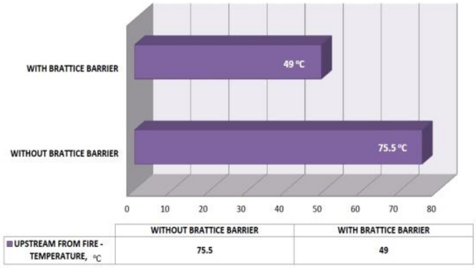

Fig. 34. Upstream from fire – Temperature

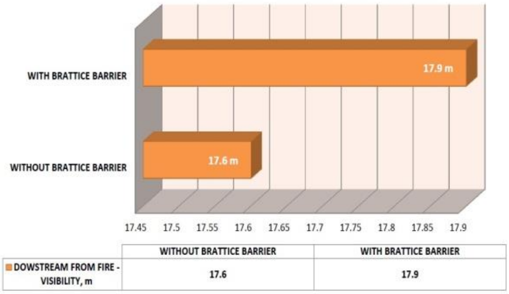

Fig. 35. Downstream from fire – Visibility

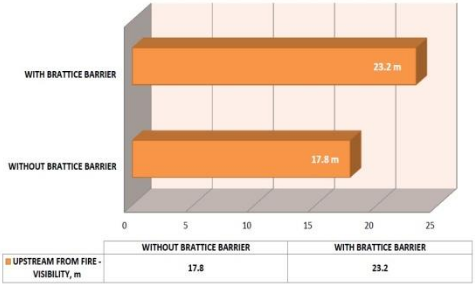

Fig. 36. Upstream from fire – Visibility

The experimental software results clearly show that the use of brattice barrier method for approaching underground mine fires is a very effective and safe method.

This experimental data suggest that the use of brattice barrier method is able to create a safe environment from which personnel can effectively extinguish the fire. In this simulated fire scenario with use of brattice barrier which has the same width as the mining roadway and 70% of the mining roadway height, installed with the existing ventilation air speed of 1 m/s, allowed for the creation of safe conditions for dealing with the fire from distance of 8 m. The use of the brattice barrier method in this case at 8 m distance from the fire enable safer upstream conditions so firefighters could approach close enough to be able to effectively extinguish the fire. Using the brattice barrier method upstream from the fire, reducied the CO concentration from 0.00085 ppm to 0.00048 ppm, reduced the SOOT concentration from 99.6 ppm to 57.5 ppm, reduced the temperature from 75.5 ^{o}C to 49 ^{o}C and increased the visibility from 17.8 m to 23.2 m.

CONCLUSION

It must be pointed out that there are quite a number of technological gaps to be resolved for effective control and fighting of mine fires. The loss of life due to mine fires has preoccupied the minds of mining engineers and scientists. In most cases the majority of deaths arising from mine fires are caused not by burns or blast effects, but by the inhalation of toxic gases, in particular, carbon monoxide. In the context of this paper the fucus has been in simulating method to create safe conditions for dealing with fires that can occur in underground mines. These methods reduced the toxic gases and heat upsteram of the fire and enable firefighters to approach close enough to extinguish the fire. In this research paper it is presented through CFD simulation the brattice barrier method of approaching underground mine fires. The results from this research shows that if we increase air ventilation speed at the mine roadway by constricting it with brattice barrier which has width as the mining roadway and 70% of the mining roadway height, we will deflect all the ventilating air into the roof section which will cool and disperse the combustion products from the fire. This brattice barrier method will then allow firefighters and mine rescue teams to approach close enough to be able to effectively extinguish the fire. Very complicated ventilation networks are often in deep mining. An effect of a fire to a ventilation system can be unforeseeable. It depend on leveling and depression balance of ventilation roads behind a fire. That's why an effect of a fire to a ventilation network should be considered on a case-by-case.

REFERENCES

ADJISKI V., 2014. *Possibilities for simulating the smoke rollback effect in underground mines using CFD software*, GeoScience Engineering, Vol. 2014 (2), 8–18.

ADJISKI V., MIRAKOVSKI D., DESPODOV Z., MIJALKOVSKI S., 2015. *Simulation and optimization of evacuation routes in case of fire in underground mines*, Journal of Sustainable Mining, Vol.14 (3), 133–143.

BANERJEE S.C., 2001. *Prevention and Combating Mine Fires*, Taylor & Francis, 48-54.

CONTI R., CHASKO L., WIEHAGEN W., 2005. *Fire Response Preparedness For Underground Mines*, National Institute For Occupational Safety And Health-NIOSH, Pittsburgh Research Laboratory, Pittsburgh, PA, 34-42.

EDWARDS C.J., HWANG C.C., 1999. *CFD analysis of mine fire smoke spread and reverse flow conditions*, Proc. of 8th U.S. Mine Ventilation Symposium, University of Missouri-Rolla, 91-99.

EDWARDS C.J., FRANKS A.R., FRIEL F.G., YUAN L., 2006. *Experimental and modeling investigation of the effect of ventilation on smoke rollback in a mine entry*, National Institute for Occupational Safety and Health Pittsburgh Research Laboratory, Pittsburgh, PA, 53-58.

Eisner H.S., Smith P.B. 1954. *Convection Effect from Underground Fires – The Backing of Smoke Against Ventilation*, SMRE RR 96.

HANSEN R., 2010. *Design fires in underground mines*, PhD thesis Mälardalen University, Sweden, 33–39.

KLOTE J., 2002. *Principles of smoke management*, American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc, 22–34.

MCPHERSON M.J., 1993. *Subsurface Ventilation and Environmental Engineering*, Chapman and Hall, 847-853.

MITCHELL D.W., 1996. *Mine Fires Prevention, Detection, Fighting*, (Intertec Publishing Inc, Chicago, IL), 19-28.

PyroSim User Manual, 2012. *PyroSim Documentation (user manual of computer code)*, Thunderhead Engineering Consultants, Inc, Manhattan, KS, USA, 125–137.

RYAN M.W., 1996. *The impact of airflow changes on the hazards of direct fighting of fires involving conveyor belting*, International conference- Safety In Mines Research Institutes, Vol. 4, 53-68.

TOTTEN G., WESTBROOK S., SHAH R., 2003. *Fuels and lubricants handbook: technology, properties, performance, and testing*, 1 ASTM International, 63–71

ZALOSH R., 2003. *Industrial Fire Protection Engineering*, John Wiley & Sons Ltd, Worcester, WA, 32-41.