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REDUCING THE FIRE AND EXPLOSION HAZARDS OF FLAME CUTTING AND WELDING IN UNDERGROUND COAL MINES

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ABSTRACT

Flame cutting and welding is one of the major causes of fires and explosions in underground U.S. coal mines. On May 20, 2006, a flame cutting operation at the Darby Mine No. 1 led to an explosion that resulted in five fatalities. On January 22, 2003, another explosion caused by flame cutting at the McElroy Mine resulted in three fatalities and three serious injuries. On June 22, 1999, a flame cutting and welding operation at the Loveridge Mine caused a fire that resulted in sealing of the mine for an extended period. Finally, on March 19, 1992, an explosion at the Blacksville No. 1 Mine that was caused by welding resulted in four fatalities.

The National Institute for Occupational Safety and Health (NIOSH) conducted a study on fires and explosions in underground U.S. coal mines that were caused by flame cutting and welding operations to determine the root causes of these types of fires and explosions. The methodology included interviewing mining personnel who perform flame cutting or welding operations in underground U.S. coal mines and visiting mines to observe these operations, and MSHA reports of investigations and accidents statistics were analyzed. The results were used to identify and compare differences between flame cutting and welding practices and techniques in small and large mines, Eastern and Western mines, low seam and high seam mines, room and pillar and longwall mines, and between experienced miners and new miners. As a result of this study, best practices and interventions were developed to reduce the number of fires and explosions caused by flame cutting and welding. This paper provides a summary of this work.

INTRODUCTION

Flame cutting and welding activities in underground U.S. coal mines continue to be a major cause of fires and explosions. Seventeen reported fires or explosions in underground U.S. coal mines for the period 1990 - 1999 were caused by flame cutting and welding activities [1]. In addition, from 2000 - 2007 six underground fires or explosions were reported that were attributed to flame cutting and welding operations and caused injuries or fatalities [2]. These fires and explosions occurred when hot sparks or hot molten metal came in contact with flammable gasses or combustible materials such as coal, oil, grease, clothing, rags, paper, aerosol cans, and other combustible materials found underground. The major source of fuel for the majority of these incidents was methane gas. MSHA's policy on 30 CFR §75.1106 states that methane tests must be made in all locations where methane is likely to exist [3].

In order to reduce the fire and explosion hazards caused by flame cutting and welding operations in underground U.S. coal mines, this study was carried out by NIOSH. The information from this study is presented as follows. In the first section of this paper, case histories of major fires and explosions in underground U.S. coal mines which were caused from flame cutting or welding operations are presented. The second section of the paper identifies and discusses the root causes of fire or explosions associated with flame cutting or welding operations. Results of flame cutting experiments performed at NIOSH's' Lake Lynn Laboratory are presented in the third section of this paper. Finally, the last section of this paper provides best practices and interventions to reduce the fire and explosion hazards of the flame cutting and welding in underground coal mining.

DARBY MINE EXPLOSION

On May 20, 2006 an explosion occurred in a sealed section of the Darby Mine No. 1, resulting in fatal injuries to five miners and injuries to one miner. A methane explosion occurred behind a block seal. MSHA determined that the explosion was caused by sparks that were generated by flame cutting of a metal roof strap that passed above the seal [4]. Figure 1 shows the type of metal roof strap that was flame cut by an oxygen and acetylene torch during the time of the explosion. Figure 2 shows the actual debris from a stopping which was destroyed by the explosion. MSHA further determined that the incident occurred because the operator did not observe basic mine safety practices and because critical safety standards were violated. Mine management failed to ensure that proper seal construction procedures were utilized in building seals, failed to ensure that safe work procedures were used while employees attempted to make corrections to an improperly constructed seal, and failed to adequately train the miners [4].

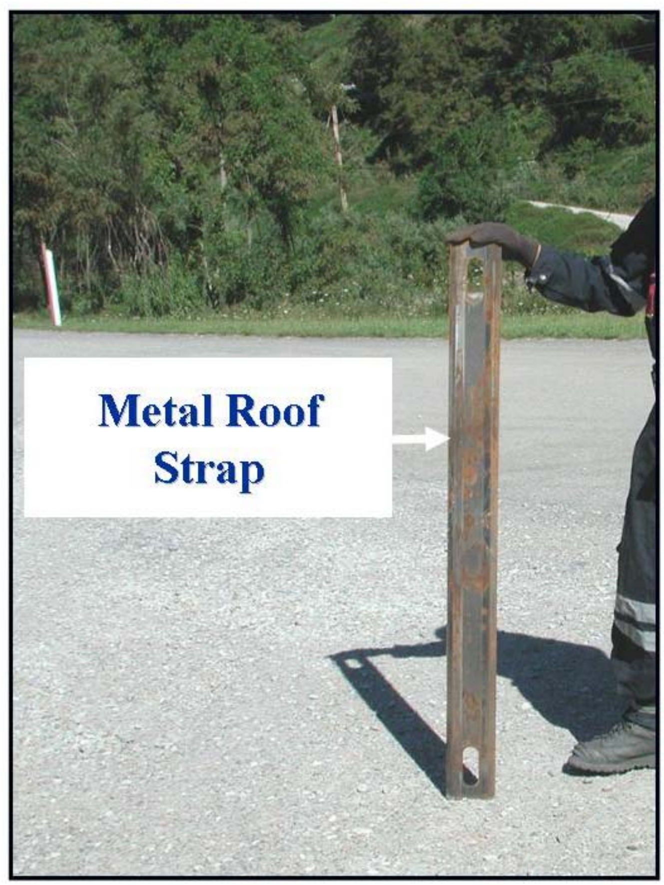

Figure 1. Metal roof strap.

Figure 2. Debris from stopping near explosion (MSHA 2006).

MCELROY MINE EXPLOSION

On January 22, 2003, an explosion occurred inside an airshaft under construction for the McElroy Mine in West Virginia. Six miners were inside the shaft at the time of the explosion. The explosion fatally injured three miners and seriously injured the three others. The miners were attempting to remove corrugated galvanized steel sheeting which blocked access to the unventilated water ring being constructed**.** Figure 3 shows the corrugated, galvanized steel sheeting after the explosion had occurred. After reading 0.2% methane on a hand held detector, the foreman directed the mechanic to cut the panning with an oxygen and acetylene torch. The mechanic ignited the torch and started to flame cut the panning. An explosion occurred when the torch cutting process ignited an explosive methane-air mixture contained inside the water ring. MSHA determined that the incident occurred because the examination for methane was not adequate. An adequate examination would have required testing for methane in all areas that could have been affected by the use of the cutting torch [5].

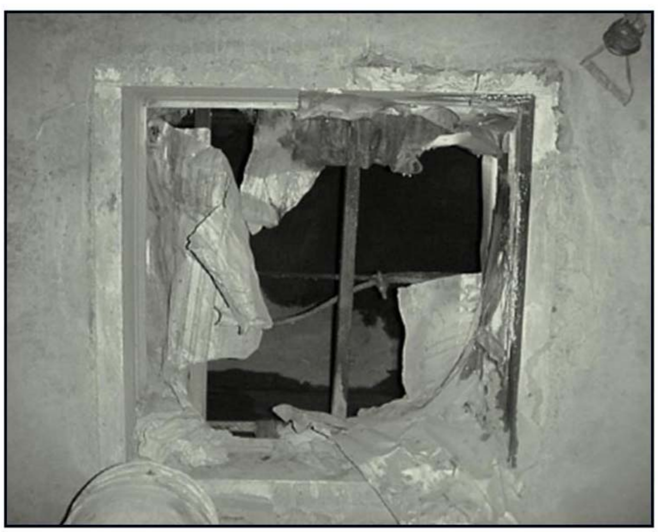

Figure 3. Corrugated, galvanized steel sheeting after explosion (MSHA 2003).

LOVERIDGE MINE FIRE

On June 22, 1999, a mine fire was discovered in an approach to a worked-out area in a former belt conveyor entry. While checking the work site where a flame cutting operation was completed at 2:00 p.m. on June 21, 1999, a foreman discovered the fire at approximately 12:50 a.m. on June 22, 1999. He observed an orange glow near a permanent stopping inby the location where the cutting operation had been performed. An attempt was made by the mine personnel to extinguish the fire; however, the fire was so intense the mine was evacuated and sealed the next day. Four days after the mine was sealed, an explosion occurred that caused major damage to ventilation structures and mining equipment. Recovery of the mine started in July 2000, and required approximately one year to complete.

MSHA's investigation concluded that that heated metal from the flame cutting operation was the ignition source. Flame cutting had been completed approximately 11 hours prior to the discovery of the fire. A heated metal spark from the cutting operation passed through an opening in the adjacent stopping and coal and other combustible material within the worked-out area were most likely ignited. The root cause of this fire was that a diligent search for fire in all potentially affected areas was not made during and after the cutting operations [6].

BLACKSVILLE MINE EXPLOSION

On March 13, 1992, a cap had been placed on a production shaft at the Blacksville No. 1 mine reducing the amount of intake air entering the shaft. On March 17, 1992, actions taken during installation of the casing caused further reductions in the amount of air entering the shaft. As a result from this reduced ventilation, methane within the explosive range (5%-15%) accumulated under the cap. On March 19, 1999, a methane explosion occurred in the production shaft, resulting in four fatalities and three injuries. MSHA's investigation determined the methane was ignited directly beneath the cap by sparks or an electric arc produced by the arc welding operation that was in progress on top of the production shaft cap [7]. The root cause of the fire was the examination for methane was not adequate.

ROOT CAUSES OF FLAME CUTTING AND WELDING FIRES AND EXPLOSIONS

To reduce or prevent fires and explosions from occurring, one must understand the nature of their initiation and identify the root causes**.** In this study the root causes of mine fires and explosions caused by flame cutting and welding operations in underground U.S. coal mines were identified. MSHA reports of investigations [4,5,6,7], MSHA Mine Accident Injury-Illness Reports, and MSHA Mining Industry Accident, Injuries Employment, Production Data Base [8] from 1995 to 2007, were analyzed. Ten working coal mines were visited to observe flame cutting and welding operations, and interviews were conducted with approximately 100 mine workers who were involved in welding tasks. In addition, flame cutting experiments were conducted at NIOSH's Lake Lynn Laboratory. The following root causes of fires or explosions from flame cutting and welding operations in underground U.S. coal mines were identified:

1. Checking for methane gas was not adequately done.
2. Searching for fire during and after flame cutting or welding was not adequately done.
3. Inspecting tools and equipment prior to starting a task was not adequately done.
4. Cleaning off combustible materials such as grease, oil, hydraulic fluid and, coal dust from the item to be flame cut or welded was not always done.
5. Making sure there was adequate ventilation at the work site was not always done.
6. Adequate training to the person performing the flame cutting or welding operation was not always provided.

FLAME CUTTING EXPERIMENTS

In order to gain a better understanding of the temperature histories of hot sparks, hot metal strips, and hot molten metal, several experiments were performed at NIOSH's Lake Lynn Laboratory. In these experiments, an oxygen and acetylene torch was used to flame cut a metal roof strap. An infrared (IR) camera with the appropriate instrumentation was used to obtain temperature histories of hot sparks and hot metal strips. In addition, a 6.35-mm thick metal strap, which was thicker then a metal roof strap, was flame cut. The cuttings and hot molten metal dropped into a pan filled with coal dust (minus 200 mesh) and grease to observe the effects of the hot molten metal on the coal dust and grease.

Temperature Histories of Hot Sparks Experiment

To conduct the experiment, a mine seal block was placed on top of the metal roof strap and the IR camera was positioned on the opposite side of the mine seal block where flame cutting was performed. Figure 4 shows this experimental setup. The metal roof strap was cut from underneath and hot particles traveled thru the two channels located on the metal roof strap. Figure 5 shows a close-up of the two channels. Figure 6 shows the IR image of several hot sparks and Table 1 lists temperatures of some of the hot sparks identified in figure 6. These experimental results showed that flame cutting can produce hot sparks with temperatures much greater than 593 °C, the minimum temperature required to ignite a methane-air mixture. It should be noted that the minimum temperature required to ignite a coal dust layer of less then 74 m (minus 200 mesh) is 160° C [9]. Table 2 lists ignition temperatures of 8 different coal layer samples.

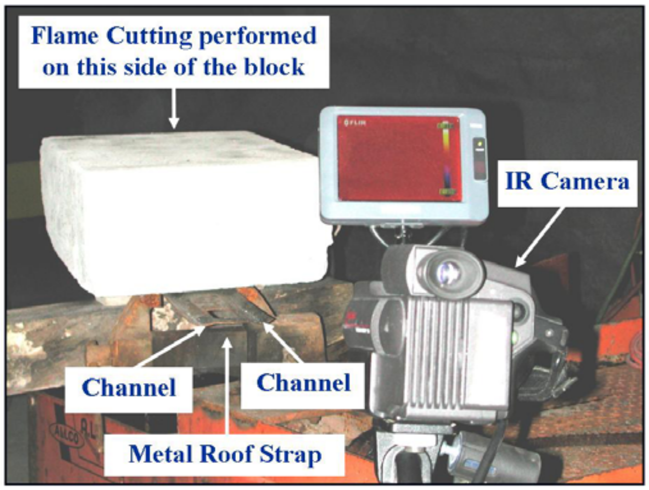

Figure 4. Setup of block and metal roof strap experiment.

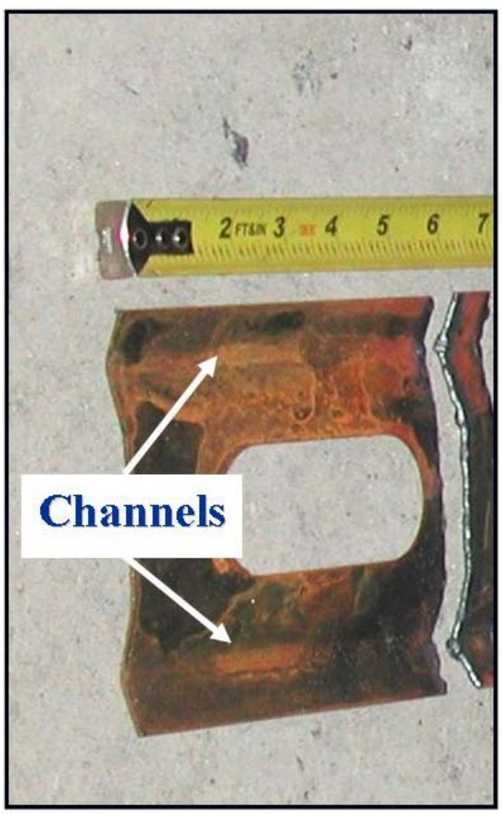

Figure 5. Close-up of the two channels on the metal roof strap.

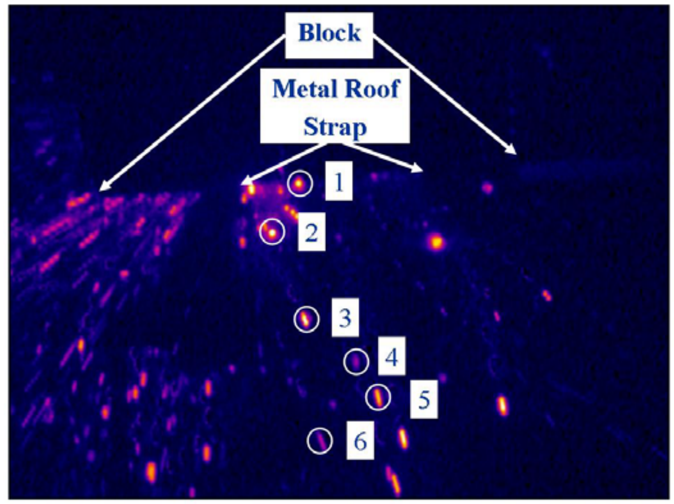

Figure 6. IR image of several hot particles.

Table 1. Temperatures of hot particles.

Hot Particle Identification	Temperature of hot particle °C
1	747
2	742
3	760
4	500
5	762
6	587

Table 2. Ignition temperature of coal layers (9).

Coal Identification	Ignition °C
lignite, California	200
lignite, North Dakota	180
bituminous, Fox Hill, CO	180
bituminous, No. 7 Illinois	160
bituminous, Whitesburg, KY	190
bituminous, Bruceton, PA	170
bituminous, Pocahontas No. 3, West Virginia	220
Bituminous, Laramie No. 3, Wyoming	180

Hot Metal Strip Experiment

In this experiment, metal strips ranging from 1.27-cm to 3.75-cm were flame cut from the metal roof strap shown in Figure 7. The temperature history of the hot metal strips was obtained by recording the temperature every 250 milliseconds using the IR camera. Figure 8 shows an example of the temperature histories of a 1.27-cm and 3.75-cm metal strip. The 3.75-cm strip's temperature remained above 593 ºC for 19 seconds and the 1.27-cm strip's temperature remained about 593 ºC for 10.5 seconds. The results from this experiment showed that these hot metal strips were capable of igniting a methane-air mixture.

Hot Molten Metal Experiment

In this experiment, the effect of hot molten metal on coal dust (minus 200 mesh) and grease was observed. Flame cutting was performed approximately 1 m above the coal fines and grease. The hot molten metal was allowed to fall directly on the coal dust and grease. The temperature of the metal and the coal dust and grease were recorded using the IR camera, shown in Figure 9. The hot molten metal immediately ignited the grease. After several minutes, flames from the grease appeared to be burned out. However, hot spots in the coal dust were observed with a temperature range between 93-145º C.

These hot spots were not visible via the human eye and were only identified by using the IR camera. The IR camera was used to monitor the hot spots for approximately two hours. After two hours, a small fan was placed near these hot spots and airflow of 400 ft/min was passed over the hot spots. This ventilation caused the temperature of the hot spots to increase, resulting in re-ignition of the coal dust and grease. The results from this experiment showed that hot spots can remain for several hours when not properly extinguished and can reignite if sufficient ventilation is provided [10]. The minimum temperature required to ignite methane-air mixture is 593° C.

Figure 7. Metal roof strap prior to flame cutting individual strips.

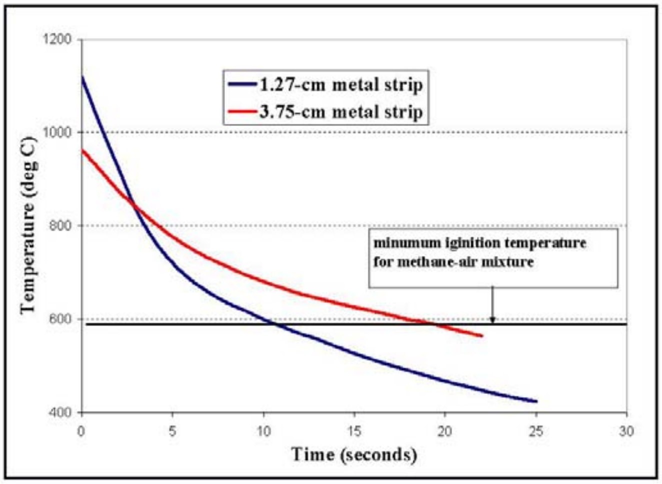

Figure 8. Temperature histories of two hot metal strips.

BEST PRACTICES TO REDUCE FIRE AND EXPLOSION HAZARDS OF FLAME CUTTING/WELDING

The code of Federal Regulations, 30 CFR §75.1106 require the following when welding, cutting or soldering with arc or flame underground. All welding, cutting, or soldering with arc or flame in all underground areas of a coal mine shall, whenever practicable, be conducted in fireproof enclosures. Welding, cutting, or soldering with arc or flame in other then a fireproof enclosure shall be done under the supervision of a qualified person who shall make a diligent search for fire during and after such operations and shall, immediately before and during such operations, continuously test for methane with means approved by the Secretary for detecting methane. Welding, cutting or soldering shall not be conducted in air that contains 1.0 volume per centum or more of methane. Rock dust (240 pounds minimum) or suitable fire extinguisher shall be immediately available during such welding, cutting or soldering [11].

The following best practices are provided to reduce the fire and explosion hazards of flame cutting and welding operations in underground coal mines. These best practices are based on the root cause analysis of fires and explosions caused by flame cutting and welding operations in underground U.S. coal mines, observing flame cutting at operating coal mines, interviews with mine workers and flame cutting experiments at NIOSH's Lake Lynn Laboratory.

Figure 9. Set-up for hot molten metal experiment.

- Persons (mine workers and contractors) who are required to conduct methane examination during flame cutting and welding operation have regular training semi-annually. This includes:
    1. The proper calibration of methane detection instruments.
    2. The proper use of methane monitors, with and without probes. Figure 10 shows a pump-type methane monitor with a probe.
- Check for methane thoroughly and continuously during the flame cutting and welding operations, and use a methane probe for hard to reach areas. Methane gas is colorless, odorless, tasteless, nontoxic, highly flammable, and is lighter then air so it can accumulate in areas such as roof cavities, get trapped underneath pan lines, and other mining equipment. Ventilation should be adequate to provide dilution of any harmful gases or toxic vapors that may accumulate.
- Persons (mine workers and contractors) whose duties include flame cutting and welding operations have regular training semi-annually on the Code of Federal Regulations and State Regulations.
- Use cold cutting alternatives versus oxygen and acetylene torch for cutting metals, when available. Several mines that were visited are using hydraulic cutters and punches. Figure 11 shows a hydraulic cutter used to cut off rusted bolts and nuts from conveyor structures at an underground coal mine.
- Have a helper to observe the flame cutting and welding operations. This helper can continuously check for methane, immediately extinguish a fire, and go for additional help if needed.
- Perform an equipment safety inspection prior to starting a flame cutting and welding operation. When using an oxygen and acetylene torch:
    1. Blow out the cylinder valves before attaching regulators.
    2. Keep all grease (fingers, gloves) away from oxygen connections.
    3. Never force connections.
    4. Use the properly sized, clean cutting tips for the operation.
    5. Check connections for leaks.
    6. Replace damaged hoses.

Figure 10. Methane monitor with probe.

Figure 11. Alternative hydraulic cutter tool for flame cutting.

7. Open cylinder valves slowly.
8. Do not use acetylene at pressures higher then 9 psi.
9. Never lay Acetylene bottles flat. They must remain vertical.
10. Ensure that flashback arrestors are installed.
11. Purge the oxygen and acetylene lines before lighting the torch.
12. When lighting the torch, point away from persons and combustibles.
13. Light the acetylene before opening oxygen valve and do not re-light the torch on hot metal with the oxygen turned on.

- Have a fire hose hooked up and charged at the cutting/welding site. Thoroughly water down the surrounding area where all hot sparks and hot molten metal can reach prior to a flame cutting and welding operation. This is one of the simplest and cheapest interventions to help reduce the risk of fire. After the flame cutting and welding operation is completed, water down the area again. Figure 12 shows a typical fire hose in an underground coal mine which can be used to water down the surrounding area.

Figure 12. Typical fire hose in an underground coal mine.

- Wipe down equipment contaminated with coal dust, oil, grease or other combustibles prior to flame cutting and welding operations.
- Apply rock dust prior to all adjacent areas to the flame cutting and welding operation after the area has been watered down. Apply the rock dust liberally to cover the entire area where hot sparks or hot molten metal may be projected to. Maintain an adequate supply of rock dust on hand to smoother any fires that may flame up during the operation.
- Maintain accurate records of the flame cutting and welding operations, including the following information:
    1. Section and exact location(s) where the flame cutting and welding operation was performed.
    2. Item or items that were flame cut or welded.
    3. The names of mine personnel that performed the flame cutting and welding operation.
    4. Time the flame cutting and welding operation started.
    5. Time the flame cutting and welding operation was completed.
    6. Special precautions taken to prevent fire or explosion, special instructions for the oncoming shift personnel to monitor the site for hot spots.

- Use a thermal image camera to check for hot spots after the flame cutting and welding activity is completed. The approximate cost for an IR camera that could be used for this application would range between $5,000 - $8,000. As mentioned earlier, hot spots can remain undetected by the human eye and are visible by an IR camera.

- Have the oncoming shift section foreman or a competent person inspect the area where flame cutting and welding operations were performed and have him or her record that the site was re-inspected.
- Discuss flame cutting and welding operations at weekly safety meetings. Discuss any concerns that you may have with this type of operation.

CONCLUSIONS

NIOSH conducted a study on fires and explosions in underground U.S. coal mines caused by flame cutting and welding operations. In this study, root causes of these types of fires were identified, flame cutting and welding operations were observed, and interviews were conducted with over 100 underground coal mine personnel who duties included flame cutting and welding operations. In addition flame cutting experiments were conducted at NIOSH's Lake Lynn Laboratory. As a result of this study, best practices are provided for reducing fires and explosions from flame cutting and welding.

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