POSITIVE PRESSURE VENTILATION: AN EMERGENCY VENTILATION TECHNIQUE FOR RAIL TUNNEL FIRES

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ABSTRACT

Positive Pressure Ventilation (PPV) is the use of high-powered blowers to remove the hostile interior environment of an enclosed structure and replace it with fresh, ambient air. Its purpose is to increase safety for fire fighters and rescue personnel, enhance the speed of fire fighting and rescue operations, and lessen property damage caused by smoke, heat, and fire.

Over the past six years, PPV has proven effective for ventilation of highway tunnels, railway tunnels, and subway tunnels. The techniques of PPV are applied with the use of a large diameter (1200-1800mm), truck or trailer mounted blowers called a mobile ventilation units (MVU). Numerous tests and actual situations in the U.S. and Europe have demonstrated the potential benefits that mobile ventilation units offer to emergency responders.

Recent incidents in the United States have increased awareness of the need for emergency ventilation tools for rail tunnels. The cross-country transport of hazardous materials via rail and the increased threat of terrorist attacks are resulting in an evaluation of emergency response procedures and equipment for tunnel firefighting.

INTRODUCTION

Positive Pressure Ventilation, or PPV as it is commonly known, is a fire fighting technique that uses air as a tool to control the hostile environment inside an enclosed structure. Small electric and gasoline-powered blowers are used to replace a hostile interior environment with fresh, ambient air. The most common blowers range in size from 18” to 27” (460mm to 690mm) in diameter and deliver from 7,000 to 24,000 CFM (11,900 m^3/hr to 40,600 m^3/hr) airflow.

PPV was first developed in the United States in the 1960’s and was used on a limited basis by progressive fire departments. In the early 1990’s, information about the use and applications of PPV became widely available and research was conducted to study the benefits it offered to fire fighters. Today, PPV is an accepted fire fighting technique and is used by fire departments and fire brigades around the world.

Since PPV works on the principle that air flows from high pressure to low pressure, a specially designed fan is used to increase the air pressure inside an enclosed structure. This is achieved by placing the fan on the outside of the structure, blowing inward, so that the cone shaped air pattern created by the fan “seals” an entrance opening and forces air into the structure (*Figure 1*). Once this seal is achieved, the air pressure increases equally at all points inside the structure.

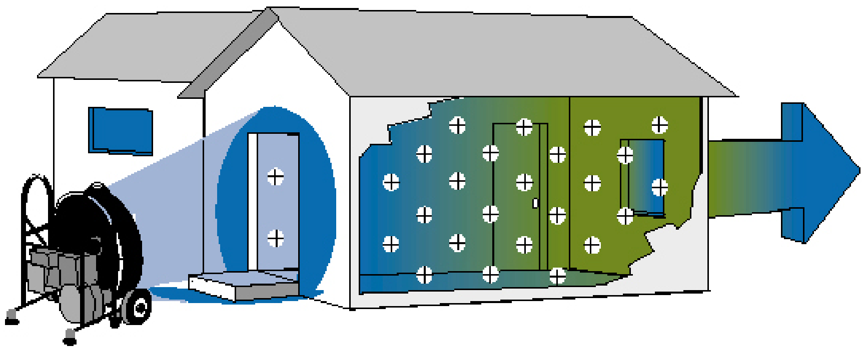

Figure 1. PPV Cone Simulation

To remove the contaminants, an exhaust opening is created near the source of the fire. The exhaust opening releases the air pressure and all of the contaminants are drawn towards this point of low pressure. The smoke, heat, and gases are replaced with fresh, ambient air. Because the positive pressure is equal at all points inside the structure, contaminants are drawn from the ceiling, floor, hallway, attic, and basement.

PPV benefits fire-fighting personnel by creating a safer environment inside an enclosed burning structure. The removal of smoke makes it easier for them to find victims and the location of the fire. The removal of heat allows them to move freely within the structure. Removal of hot gases reduces the possibility of flashover. Ultimately, PPV benefits victims by increasing their chances of survival.

PPV AND TUNNEL FIRE FIGHTING

Of all large structure fires, tunnel fires can present the greatest challenges. Heat and smoke can quickly develop to a level that reduces survivability and hampers fire fighting operations. Getting close enough to apply water to a fire can be difficult as the temperature inside the tunnel exceeds that which personal protective equipment can withstand. Search and rescue personnel attempting to locate victims are at greater risk because of the time required to get into and out of a tunnel.

As with other structures, PPV can be effectively applied to ventilate a tunnel during a fire. Mobile ventilation units ranging in size from 48" t0 72" (1200mm to 1800mm) in diameter, which produce from 80,000 to 160,000 CFM (135,000 m^3/hr to 272,000 m^3/hr) air output.

To achieve an entrance opening seal (as in *Figure 1*), the mobile ventilation unit is placed 20 to 30 meters away from the tunnel portal and elevated so that the fan is located approximately in the center of the tunnel bore (*Figure 2*). As the air cone expands to match the inside diameter of the tunnel bore, the tunnel becomes sealed. Once the entrance is sealed, the tunnel becomes positively pressurized. As mentioned earlier, the flow is from high pressure to low pressure, which means the smoke, heat, and gases are forced to the opposite, un-pressurized end of the tunnel.

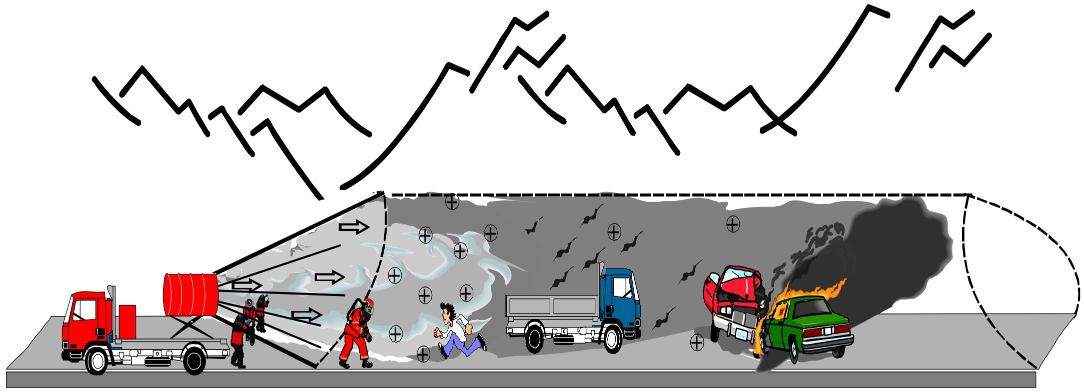

Figure 2, PPV Blower Placement for Tunnel Fire Fighting.

Once ventilation has started, fire and rescue personnel can walk directly to the location of the fire with clear visibility and greatly reduced temperatures (*Figure 3*). The fire can be extinguished quickly and survivors can be rescued. If a situation arises that forces fire and rescue personnel to evacuate the tunnel, they have a clear path of fresh air to follow to safety.

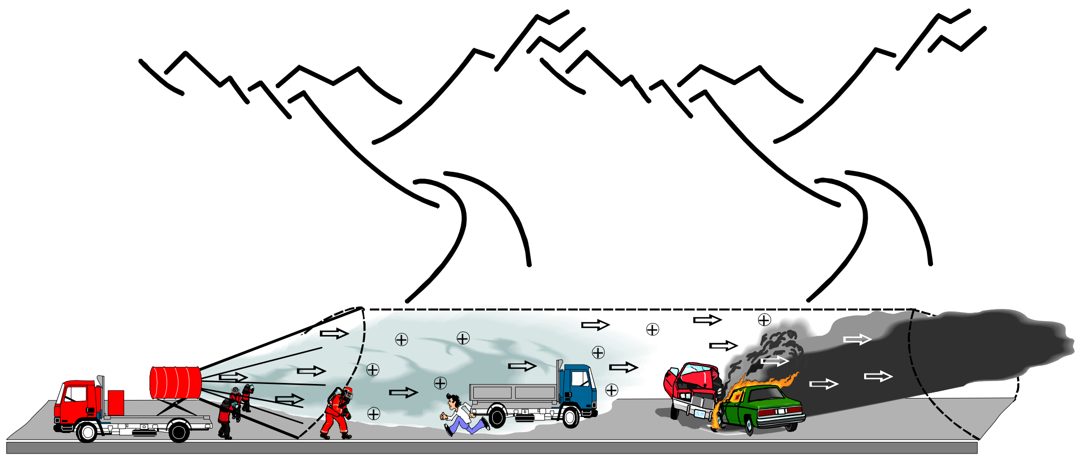

Figure 3, PPV Ventilation During Tunnel Fire

Victims capable of self-rescue can be helped with the application of PPV. The environment inside a tunnel will begin to improve the instant that PPV is applied. Regardless of their location or direction of travel, heat will be reduced, harmful gases will be ventilated, and chances of survival will improve dramatically.

DETERMINING THE DIRECTION OF TUNNEL VENTILATION

Once the decision to use PPV has been made, the direction of ventilation must be determined. In order to have a choice of ventilation directions, response agencies on each end of the tunnel must have access to equipment for PPV or there must be a way to place an MVU at either end of the tunnel. The following issues must be considered:

1. **The approximate location of the fire within the tunnel.**

PPV is most effective when the contaminants travel the shortest possible distance to the exhaust opening. If a fire is located near a tunnel portal, ventilation should be initiated from the opposite end of the tunnel. In some cases, the priority is getting fire fighters to the seat of the fire as quickly as possible which would require venting from the portal nearest the fire.

2. **The slope of the tunnel.**

Hot smoke in a tunnel with a steep slope will flow towards the higher elevation due to buoyancy. When possible, it is important for fire and rescue personnel to use this to their advantage. In cases where the direction of ventilation must go downhill, against the natural flow of smoke, PPV has the ability to overcome the buoyancy by changing the air pressure within the tunnel.

3. **Wind direction and velocity.**

Strong headwinds can have a negative impact on the effectiveness of PPV. Conversely, a strong tailwind can have a positive impact. It is best to use the wind to an advantage if possible. In the event of a strong cross wind at the entrance opening, the direction of the fan duct must be turned into the wind to compensate for the cross wind.

PPV AS A SUPPLEMENTAL VENTILATION SYSTEM

PPV is not intended to replace jet fans or fixed ventilation systems. It is recommended as an alternative or supplement to current technologies. PPV can be applied in the following situations:

1. **When a tunnel does not have a fixed ventilation system in place.**

There are many tunnels with no emergency ventilation system installed. The technology was either not available at the time that the tunnel was built or it was deemed unnecessary by the tunnel designers. When the agencies responsible for protecting these tunnels have access to an MVU, they greatly enhance their ability to manage an incident.

2. **When the fixed ventilation system in a tunnel is not operational.**

Fixed emergency ventilation systems, including jet fans, are designed to withstand the extreme conditions that exist inside a tunnel during a fire. However, there are limitations to the length of time that they will continue to function in this environment. In the event that a fixed system fails due to prolonged exposure to extreme heat, an MVU is capable of providing PPV to the tunnel. The length of time that PPV can be applied is unlimited, as long as the MVU has enough fuel.

3. **To supplement and enhance a fixed ventilation system.**

In some cases, a tunnel emergency ventilation system designed to control exhaust from vehicles may not be effective for controlling heat and smoke from a fire. In these cases, an MVU can be an effective supplement to this system.

INTRODUCTION OF WATER MIST FOR COOLING

Introducing water to the air stream of a PPV fan unit can enhance the reduction of heat inside a tunnel. By installing a high-pressure misting ring in the middle of the air stream, water mist can be carried in the air to improve cooling. Breaking the water down to a very small droplet size increases the surface area, improving the heat absorption properties of a given amount of water. Water flow averaging only about 275 liters per minute can absorb 20,000 kJ/sec.

TEST REPORT: CNR MEMORIAL TUNNEL

On June 27, 2002, the Center for National Response conducted tests of the capabilities of a mobile ventilation unit for emergency ventilation at the Memorial Tunnel in West Virginia. The Memorial Tunnel test was the first U.S.-based test of a mobile ventilation unit and PPV for tunnel ventilation. Numerous live fire tests have been conducted in Europe that successfully proved the benefits of PPV for tunnel emergencies.

The CNR tunnel is 2,785 feet long, 28.4 feet wide, 28 feet high at peak and runs generally from southeast to northwest at a 3.2º positive slope. June weather in West Virginia is variable with an average high temperature of 76ºF and an average low temperature of 56ºF. The temperature inside the tunnel is a constant 56ºF.

Test operators for this test series were firefighters from the 130th Airlift Wing (AW), Charleston, West Virginia Air National Guard (WVANG). None of the operators had any previous experience operating the mobile ventilation unit under test

Two electric smoke generators were started at the 1,400 foot position and run for ten minutes for each test. This caused visibility to be totally obscured in the immediate area (a 200 foot wide cloud of smoke).

Test Objective

The objective of the test was to examine the ability of the test operators to utilize the mobile ventilation unit to provide PPV and eliminate smoke from the tunnel. Prior to testing, the tunnel was smoked starting at the 1,400 foot marker. Test operators conducted a survey of the incident site and initiated PPV (North to South). Wind speed and visual acuity were taken at set markers.

Test Results

The MVU was positioned 40 feet outside the North Portal entrance. Upon initiation of PPV, wind speed at the 2,200 foot marker increased to 2.53 MPH. Within 10 minutes, the majority of the smoke had moved to the South Portal entrance of the tunnel. After 23 minutes, test controllers determined that the tunnel was clear of smoke and the test was concluded. The obstructions in the tunnel (trailers, vehicles, small buildings, etc.) did not significantly affect the performance of the MVU. The test proved that the MVU could quickly create a clear path to the seat of the fire, allowing firefighters faster access in a safer environment.

INCIDENT REPORT: TRAIN DERAILMENT IN RAIL TUNNEL NEAR PITTSBURGH, PA

On Wednesday, October 10, 2001, twelve “hopper” rail cars hauling 2.5 million pounds of grain corn derailed 1,000 feet into a one-mile long tunnel just outside the city of Pittsburgh, Pennsylvania.

The crew for the train was able to disconnect the locomotives and pull away from the wreckage leaving the tunnel safely. The railroad’s concern at this point was clearing the railway as quickly as possible, making the necessary repairs, and opening the tracks to normal traffic.

The tunnel is approximately one mile long, 20 feet wide and 30 feet high at the center. About one-half mile into the tunnel from the south entrance, the track begins to curve gradually to the left (west). There is very little, if any, grade to the tracks.

There was no natural ventilation in the tunnel due to the fact that the portals of the tunnel were located at the ends of three-quarter mile long “ravines” or cuts. The clean up crews would be using heavy equipment producing large amounts of diesel exhaust fumes. It was also apparent that unloading the 2.5 million pounds of grain corn from the derailed train cars would create very dusty and possibly hazardous conditions within the tunnel. The need for forced ventilation was evident

The emergency response contractor responsible for the clean up utilized a 48” diameter mobile ventilation unit to provide ventilation. The unit would be used to protect workers from hazardous fumes and dust during the removal of the cargo and rail cars.

The mobile ventilation unit was positioned next to the tracks approximately 30 meters from the South tunnel portal (the South portal was chosen because this location provided the easiest access to the tracks). The ventilator was elevated twelve feet above the track bed and aimed toward the center of the tunnel bore. This position allowed the MVU to seal the entrance opening while keeping the tracks clear for equipment entering the tunnel.

A digital anemometer was used to measure air movement both outside and inside the tunnel. The initial readings of air movement in the tunnel were zero velocity. Once ventilation was started, the air velocity at the South portal was measured at 18.1mph. This measurement was taken from the center of the track bed and eight feet above the ground.

Location	Wind Speed
At the South Portal	18.1 mph (entrance opening)
40 feet inside tunnel	11.0 mph
60 feet inside tunnel	8.5 mph
80 feet inside tunnel	7.0 mph
100 feet inside tunnel	5.6 mph
At the North Portal	3.9 mph
100 feet inside tunnel	3.4 mph (exhaust opening)

It should be noted that the grain removal equipment and twelve derailed hopper cars were still in the tunnel and were blocking a majority of the tunnel bore.

Air quality in the tunnel was monitored during the operations to ensure a safe work environment. Air quality in the tunnel was never a question once the MVU was put into operation as the salvage efforts continued. This was the case even though much more, and much heavier, diesel equipment was used in the tunnel in removing the final derailed cars.

During most incidents of this type, workers are forced to work in a hostile environment with the assistance of breathing apparatus or respirators. By applying PPV with a mobile ventilation unit, the need for supplemental breathing equipment is reduced, the overall air quality inside the tunnel is improved, and a safer work environment is created.

ANALYSIS: THE BALTIMORE TUNNEL FIRE

The fire that occurred in the Howard Street tunnel in Baltimore on July 18, 2001 was one of the worst tunnel fire incidents in the United States in recent years. The fact that the fire burned so hot for so long in the center of a major metropolitan area caused millions of dollars in damage and generated a tremendous amount of media attention.

One of the reasons the fire was so severe was the fact that fire fighters had a very difficult time reaching the seat of the fire. Dense smoke and temperatures estimated at 1,000-1,500 degrees Fahrenheit made it nearly impossible for fire fighters to approach the fire from either end of the tunnel.

Further hampering firefighting efforts was the fact that the train’s cargo included hazardous chemicals, which needed to be offloaded before the cars could be removed from the tunnel. Due to the extreme temperatures, the equipment used to remove the chemicals would not function.

According to an article by Michael Ettlin of the Baltimore Sun, firefighters couldn't neutralize the acid leak in the normal way, by spreading an alkaline chemical to neutralize it. In the presence of heat, the combination would have been explosive. Nor could they pump out the chemical. The plastic pumps that have to be used to pump acid chemicals would have melted. To cool the acid, firefighters opened a manhole cover above the rail car and sprayed the car with water for about two hours.

Positive Pressure Ventilation could have had a dramatic impact on the firefighter’s ability to fight the Baltimore Tunnel Fire. By positioning a mobile ventilation unit at either end of the tunnel, fire fighters could have quickly created a clear path to the seat of the fire. In addition, they would be removing the heat and smoke that made reaching the fire so difficult.

Positive Pressure Ventilation could have allowed the fire fighters to take control of the fire in much less time, reducing damage to the tunnel and disruption of the city of Baltimore.

CONCLUSIONS

1. PPV is a proven ventilation technique that offers clear benefits for fire and rescue personnel when fighting tunnel fires. The main challenges that tunnel fires present are poor visibility and extreme heat. The nature of tunnel construction makes it difficult to overcome both of these. The application of PPV can quickly and effectively reduce heat, improve, visibility, and create a safer environment for fire and rescue personnel. There are also clear benefits to victims.

2. The mobile ventilation unit is an effective tool for applying PPV during tunnel fire fighting operations. Because the MVU is located outside of the tunnel during a fire, it is not subjected to the extreme conditions that exist within the tunnel. Additionally, it is possible to calculate the size and quantity of mobile ventilation units required for specific tunnel to ensure that adequate ventilation is achieved.

Further research and testing are required to develop operational and tactical guidelines for fire and rescue personnel to follow. As with any fire fighting tool, training and coordination of personnel are important for safe and effective operations.

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