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REFUGE ALTERNATIVES RELIEF VALVE TESTING AND DESIGN

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ABSTRACT

The National Institute for Occupational Safety and Health (NIOSH) has been researching refuge alternatives (RAs) since 2007. Refuge alternatives typically have built-in pressure relief valves (PRVs) to prevent the unit from reaching unsafe pressures. The Mine Safety and Health Administration (MSHA) requires that the PRVs vent the chamber at a maximum pressure of 1.25 kPa (0.18 psi, 5.0 in. H_2O), or as specified by the manufacturer. To facilitate PRV testing, an instrumented benchtop test fixture was developed using an off-the-shelf centrifugal blower and ductwork. Relief pressures and flow characteristics were measured for three units: a modified PVC check valve, an off-the-shelf brass/cast iron butterfly check valve, and a commercially available valve that was designed specifically for one manufacturer's steel pre-fabricated RA and has been adapted for use in built-in-place (BIP) RAs located at one mine. PRVs used in tent style RAs were not investigated. The units were tested with different modifications and configurations in order to check compliance with 30 CFR regulations.

BACKGROUND

The Mine Improvement and New Emergency Response Act of 2006 (Miner Act) (1) was enacted in the wake of three mine explosions/fires that claimed 19 lives that year. Intended to help improve underground coal mine accident preparedness, the MINER Act includes provisions that target mine safety issues in areas such as emergency response planning, adoption of new technology, training and education, and mine safety standards enforcement. Section 13 of the MINER Act specifically directed the National Institute for Occupational Safety and Health (NIOSH) to provide for research into the effectiveness and viability of refuge alternatives (RAs) for underground coal mines, and the Department of Labor to act on the results of such research as appropriate. These mandates culminated in the 2009 adoption of changes to 30 CFR mining health and safety regulations, requiring underground coal mines to provide mine emergency RAs and associated components, to provide a life-sustaining environment for persons trapped underground. Such RAs can be either self-contained mobile units or built-in-place (BIP) facilities. The regulatory changes also include provisions establishing requirements for the Mine Safety and Health Administration (MSHA) approval of RAs and their components, and among these provisions are numerous criteria for providing a safe breathable atmosphere under positive pressure within the RAs. One specific criterion for maintaining a safe RA atmosphere requires the inclusion of an air pressure relief valve that will activate at a maximum of 1.25 kPa (specified as 0.18 psi, or approximately 5.0 in H_2O), or at a pressure as specified by the RA manufacturer, above mine atmospheric pressure in the RA (2).

The primary purpose of the required relief valve is to limit the maximum positive pressure within the RA to prevent damage to RA systems or components as well as provide for occupant safety and comfort during use. Relief valve design and operation, however, must also account for other critical factors such as meeting minimum RA airflow requirements based on maximum occupancy, preventing reverse airflow before positive pressure is established or if it is lost during RA use, surviving MSHA-specified overpressure and flash fire conditions prior to RA deployment, preventing an overpressure that may interfere with personnel entry and exit of the RA, and in some cases allowing necessary unobstructed airflow prior to RA deployment.

Research to date by the NIOSH Office of Mine Safety and Health Research (OMSHR) studying mobile RAs, as well as built-in-place RA installations for coal mining, suggests that the design and implementation of RA relief valves has not yet had sufficient performance analysis or technical development. In response to this need, OMSHR has begun studying and testing the application of relief valves for RAs. Work thus far has focused primarily on the relief pressure and flow characteristics of a commercially available purpose-built RA relief valve, as well as adaptations of two relief valve designs normally used in other applications. This paper details the laboratory testing and specially built apparatus by which relief pressures have been measured and studied while controlling valve configurations, flow levels, and duct characteristics. Valve design reliability, adequacy of valve flow capacity, and valve survivability for overpressures and flash fires have not yet been addressed under this research, but the testing reported here lays the groundwork for such follow-up research.

EXPERIMENTAL SETUP

A pressure relief valve test stand (PRVTS) was developed in order to test the performance of a variety of relief valves. The PRVTS consists of a 1.12-kW (1.5-hp) centrifugal blower fan that can produce a maximum pressure of 1.62 kPa (6.5 in. H_2O) at 24.9 m^3/min (880 ft^3/min), standard 10.2-cm (4.0-in) and 12.7-cm (5.0-in) ductwork, candidate pressure relief valves (PRVs), a pressure gauge, and an air velocity transducer, as shown in Figure 1. A photo of the test setup is shown in Figure 2. The blower fan provides the airflow to test each relief valve. The bleed off leg and gate provide a means to reduce the flow to the relief valve. The pressure gauge and airflow transducer provide the operating parameters of the relief valve being tested. The different angle configurations provide different relief pressures and flows depending on the angle of the flap and resulting force required to open the relief valve.

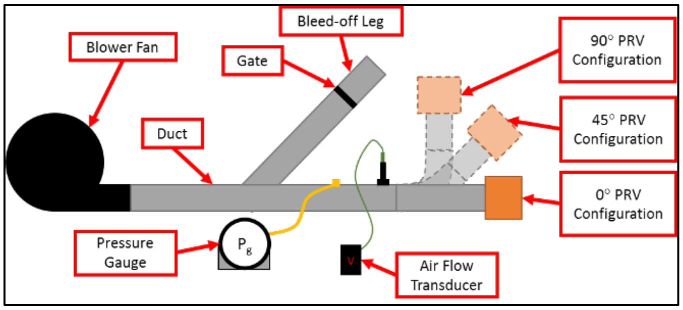

Figure 1. PRVTS setup.

The system is modular in that ductwork can be extended or reduced and PRVs can be quickly switched out. This allowed for PRVs to be tested at 0°, 45°, and 90° orientations (angle of flow with respect to horizontal).

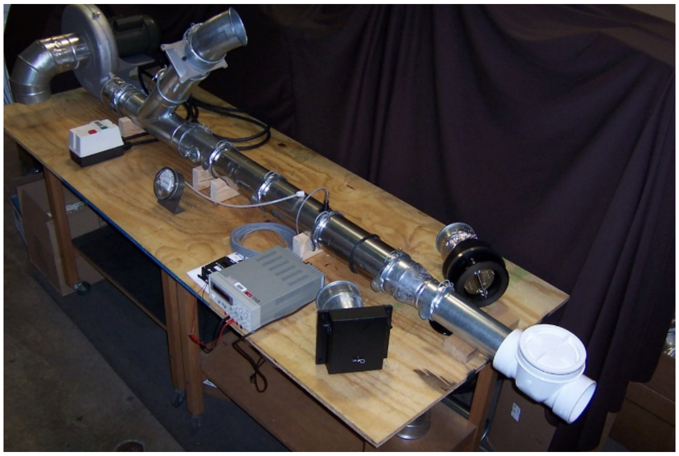

Figure 2. PRVTS setup photo.

The pressure at which the PRV relieved was measured using a Magnehelic gauge rated up to 2.5 kPa (10.0 in. H_2O). A modular airflow probe adapter was designed and fabricated with a 3D printer which allowed for the probe to be positioned at various distances from the center of the duct by installing different sized inserts. An example of one insert is shown in Figure 3. The air velocity was measured using an air flow transducer, as shown in Figure 4. Four different inserts were tested to measure the air velocity at distances of 0.0 mm (0.0 in), 12.7 mm (0.5 in), 25.4 mm (1.0 in), and 38.1 mm (1.5 in) from the center of the duct. Measuring the air velocity at these four locations allowed for the average velocity to be determined across the ductwork cross section. The average velocity for the PVC check valve was within 10% of all measured velocities, making multiple readings unnecessary for the other relief valves.

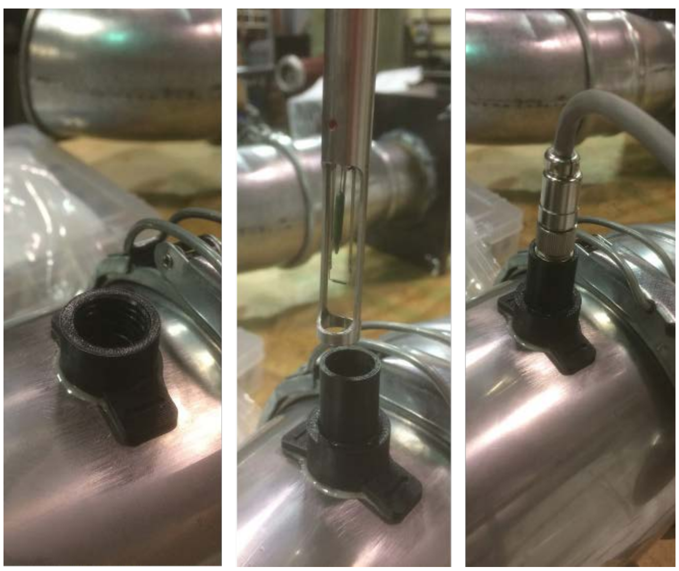

Figure 3. Left to right: probe adapter, probe adapter with insert, probe installed ready for testing.

VALVE DESIGNS

Several valve designs were tested using the bench top setup. A commercially available 10.2-cm (4.0-in) Schedule 40 PVC check valve (Figure 5) was tested in its original configuration and modified to increase the relief pressure. These valves are normally used in water systems to prevent backflow in wastewater applications. Weights were added to the plastic check valve flap and tested in different orientations. The flap seals with an O-ring that is captured in the outer edge of the flap. A brass/cast iron butterfly check valve (Figure 6) was modified by removing the torsion springs to lower the relief pressure to an acceptable level and orienting the valve to use the weight of the brass parts to create a relief pressure. These valves are also used for backflow prevention in wastewater systems. A commercially available valve that was designed for RAs and is currently installed in production mines (Figure 7) was also tested. The valve was tested in as-received condition as well as a modified configuration that aimed to reduce the relief pressure in an attempt to meet the 30 CFR (3) maximum opening pressure of 1.25 kPa (0.18 psi). The unit is steel cased and has a steel flap design that is spring loaded and sealed with an elastomer gasket.

Figure 4. Air flow transducer.

Figure 5. PVC check valve.

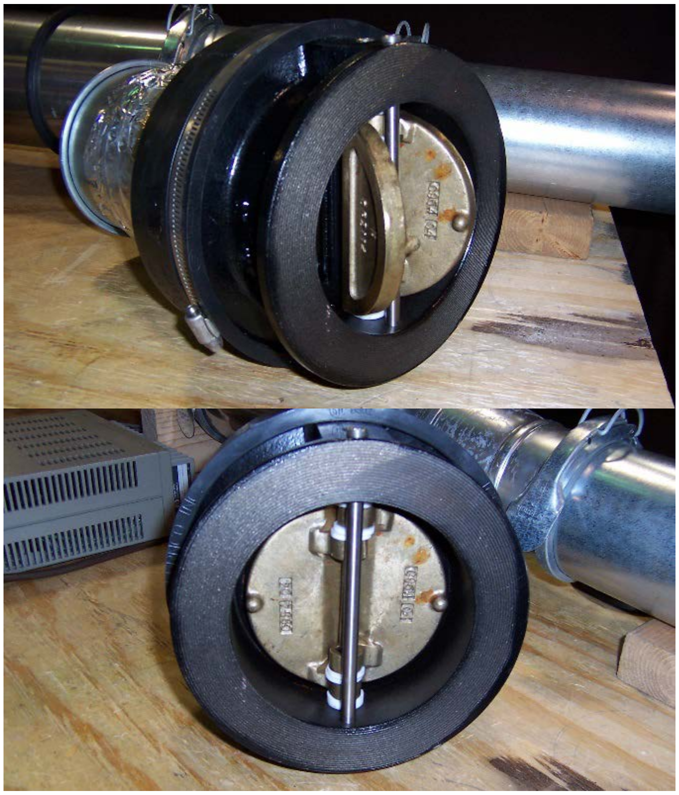

Figure 1. Brass/Cast iron butterfly check valve.

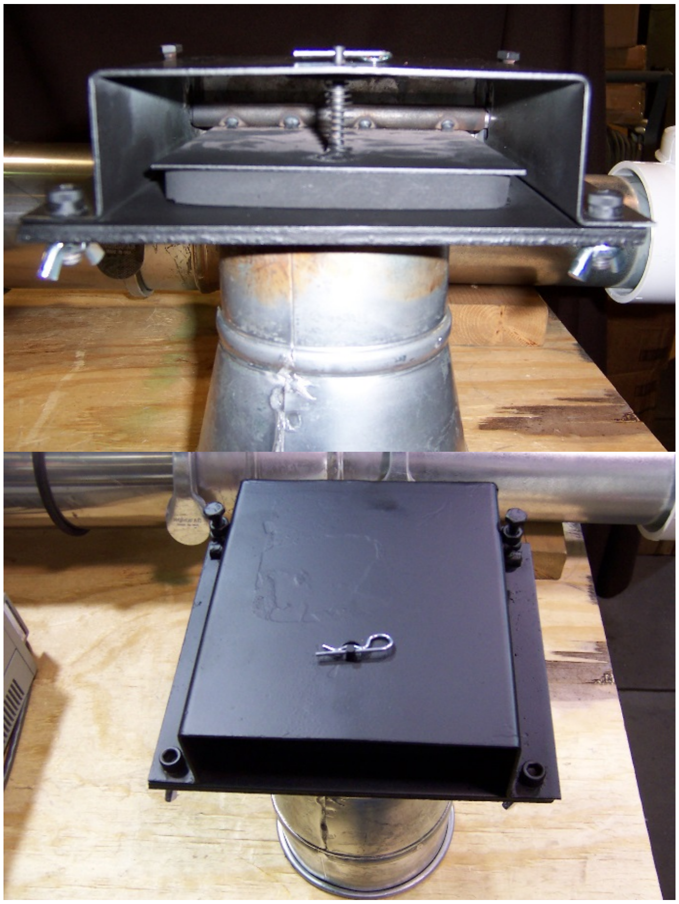

Figure 2. Commercially available relief valve.

Table 1. Pressure and velocity data for the NIOSH-modified PRV.

		XL Insert (1.5" from center)			L insert (1.0" from center)			M insert (0.5" from center)			S insert (0" from center)			Average		
Angle	Added weight to flapper (kg)	V (m/s)	Q (m^3/min)	P (kPa)	V (m/s)	Q (m^3/min)	P (kPa)	V (m/s)	Q (m^3/min)	P (kPa)	V (m/s)	Q (m^3/min)	P (kPa)	V (m/s)	Q (m^3/min)	P (kPa)
0°	0.00	21.4	16.3	0.3	23.0	17.5	0.3	22.9	17.4	0.3	23.7	18.0	0.3	22.8	17.3	0.3
	0.43	20.0	15.2	0.5	19.9	15.1	0.5	21.0	16.0	0.5	20.9	15.9	0.5	20.4	15.5	0.5
	0.87	18.9	14.3	0.7	19.5	14.8	0.7	20.9	15.9	0.7	20.0	15.2	0.7	19.8	15.1	0.7
45°	0.00	20.9	15.9	0.3	23.2	17.6	0.3	23.0	17.5	0.3	23.8	18.1	0.3	22.7	17.3	0.3
	0.43	19.7	15.0	0.6	21.5	16.4	0.6	21.4	16.3	0.6	22.1	16.8	0.6	21.2	16.1	0.6
	0.87	18.3	13.9	0.7	20.0	15.2	0.7	19.9	15.2	0.7	20.8	15.8	0.7	19.8	15.0	0.7
90°	0.00	21.1	16.0	0.3	22.3	16.9	0.3	22.4	17.0	0.3	23.8	18.1	0.3	22.4	17.0	0.3
	0.43	21.9	16.6	0.4	21.3	16.2	0.4	22.9	17.4	0.4	22.3	17.0	0.4	22.1	16.8	0.4
	0.87	19.7	15.0	0.5	22.4	17.0	0.5	22.5	17.1	0.5	21.7	16.5	0.5	21.6	16.4	0.5

MEASUREMENTS AND ANALYSIS

The PRVTS was used to measure the pressure and air velocity for a number of configurations. Three different PRVs were tested as described above. NIOSH researchers modified an off-the-shelf PVC check valve by adding weights to the lightweight flapper to increase resistance to air flow. This allowed for the relief pressure to be controlled by simply adding or removing weights and changing the angle. The test results are shown in Table 1. Note that all values were recorded after airflow was established and had stabilized. Nine configurations in total were tested by adjusting the angle and the amount of weight added to the flapper. The air velocity was measured using all four of the different velocity probe inserts at all nine configurations. The volumetric flow rate was calculated based on the cross-sectional area of the 10.2-cm (4.0-in) ductwork at the PRV. The air velocity was corrected for the ductwork reduction using the Venturi principle (Continuity Equation) (4):

$$Q = v_1 A_1 = v_2 A_2$$

Q – Flow rate (cubic meters/second),
v – velocity (meters/second),
A – cross-sectional area of pipe (square meters)

The results in Table 1 show the effects of changing the angle in conjunction with the weights. This shows that the relief pressure can be adjusted up or down within the MSHA requirements as desired.

The results of the brass/cast iron butterfly PRV are shown in Table 2. Two different configurations were tested for this unit:

- At 45° with no spring return
- At 90° with no spring return

For both configurations, the air velocity was measured at the center of the ductwork. The unit was not tested at 0° because it would not be capable of sealing without a spring return. For the 45° configuration, the pressure relieved right at the 30 CFR limit of 1.25 kPa (5 in H_2O). For the 90° configuration, the pressure exceeded the 30 CFR limit.

Table 2. Brass/cast iron butterfly PRV test results.

Angle	Configuration	V (m/s)	Q (m^3/min)	P (kPa)
45°	No springs	15.1	11.5	1.25
90°	No springs	14.1	10.7	1.30

Test results for the commercial PRV (purpose-built for RAs) are shown in Table 3. For this particular unit, NIOSH researchers tested three different configurations:

- Original (as received)
- Removal of preload washers
- Replacing the factory spring with a 17.9-g/mm (1-lb/in) spring and a washer

Table 3. Commercial PRV test results.

Angle	Configuration	V (m/s)	Q (m^3/min)	P (kPa)
0°	Original	0.0	0.0	1.62
	Remove preload washers	0.0	0.0	1.62
	Replace factory spring with 1 lb/in spring + washer	11.3	8.6	1.44

For all three configurations, the air velocity was measured at the center of the ductwork. The pressure exceeded the limit of 1.25 kPa (5.0 in H_2O) for all three configurations. The most noteworthy result from this testing is that this unit did not relieve any pressure up to 1.62 kPa (6.5 in H_2O, maximum pressure available for the test apparatus) in the original configuration. Even with modifications to reduce the load on the valve by replacing the spring, the unit did not relieve until 1.44 kPa (5.8 in H_2O). The manufacturer was contacted and stated the valve was not calibrated. The users of this commercially available RA valve did pass purge testing (for a portable RA) during their harmful gas removal component testing. The valve was only tested at the 0° angle because the other angles would have increased the relief pressure due to the weight of the flap.

Although the adequacy of RA relief valve flow capacity has not been yet been addressed directly in this research, the test results just presented do begin to shed light on this topic. Specifically, 30 CFR requires an airflow of at least 0.35 m^3/min (specified as 12.5 ft^3/min) per occupant to a BIP RA *when breathable air is supplied by compressed air cylinders, a fan, or a compressor*. The modified PVC check valve configured at 45° with no added weights represents a breathable air throughput sufficient for approximately 49 RA occupants.

DISCUSSION

The testing consisted of three different valve designs to be used for pressure relief in BIP RAs. Two of the units were purchased off-the-shelf and modified (a PVC check valve and a brass/cast iron butterfly check valve) to evaluate compliance with the 30 CFR regulations for relief pressure. A commercially available valve that was designed for steel portable RAs and currently installed in a number of mines was also examined. Of the three PRVs tested, only the modified PVC check valve complied with the 1.25 kPa (0.18 psi, 5.0 in. H_2O) limit. The commercially available valve would not operate at the test setup maximum pressure of 1.62 kPa (6.5 in H_2O) until a lighter spring was installed, although the relief pressure was still above the 30 CFR limit. This manufacturer did demonstrate the ability to purge with this valve installed in a portable RA, in previous testing. Additionally, the airflow through the PVC check valve as tested is sufficient to meet the BIP RA requirement of 0.35 cubic meters/minute (12.5 ft^3/min) per RA occupant, for RA capacities as high as 49 people.

It should be noted that the purpose of the testing conducted in this paper was to investigate the airflow and pressure relief characteristics of the aforementioned PRVs. No research has been performed on the survivability of said PRVs to comply with the 103 kPa (15.0 psi) impulse overpressure specification. Future research is necessary to address the survivability of PRVs and may warrant significant valve housing and flap redesign.

CONCLUSIONS

The commercially available valve tested is used in steel pre-fabricated portable RAs and one mine operators' BIP RA. The vast majority of pressure relief valves in use service tent type units and were not part of this research. The commercially available relief valve does not comply with the 1.25-kPa (0.18-psi) limit but may meet specifications set by the manufacturer. This valve needs to be reevaluated by the manufacturer to ensure it meets the 30 CFR specifications. The PVC check valve described here offers a viable solution for relief valves in RAs. It can be modified to adjust the relief pressure as needed. The size of the relief valve can be chosen to allow sufficient airflow out of the RA to meet the airflow requirement based on the number of miners in the chamber. The brass/cast iron butterfly check valve may be an alternative to the PVC check valve with further modifications. Future research is necessary to examine the survivability of PRVs subjected to a 103-kPa (15.0-psi) impulse overpressure. The PVC check valve housing and flap may need to be redesigned in order to withstand the mine atmosphere and a potential catastrophic event.

DISCLAIMER

The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health. Reference to specific brand names does not imply endorsement by the National Institute for Occupational Safety and Health.

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