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Refuge alternatives relief valve testing and design with updated test stand

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Abstract

Underground refuge alternatives require an air source to supply breathable air to the occupants. This requires pressure relief valves to prevent unsafe pressures from building up within the refuge alternative. The U.S. Mine Safety and Health Administration (MSHA) mandates that pressure relief valves prevent pressure from exceeding 1.25 kPa (0.18 psi), or as specified by the manufacturer, above mine atmospheric pressure when a fan or compressor is used for the air supply. The U.S. National Institute for Occupational Safety and Health (NIOSH) tested a variety of pressure relief valves using an instrumented test fixture consisting of data acquisition equipment, a centrifugal blower, ductwork and various sensors to determine if the subject pressure relief valves meet the MSHA requirement. Relief pressures and flow characteristics, including opening pressure and flow rate, were measured for five different pressure relief valves under a variety of conditions. The subject pressure relief valves included two off-the-shelf modified check valves, two check valves used in MSHA-approved built-in-place refuge alternatives, and a commercially available valve that was designed for a steel refuge alternative and is currently being used in some built-in-place refuge alternatives. The test results showed relief pressures ranging from 0.20 to 1.53 kPa (0.03 to 0.22 psi) and flow rates up to 19.3 m^3/min (683 scfm). As tested, some of the pressure relief valves did not meet the 1.25 kPa (0.18 psi) relief specification.

Introduction

The Mine Improvement and New Emergency Response Act of 2006 (MINER Act) was enacted in the United States 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 (U.S. Mine Safety and Health Administration, MSHA, 2006). Section 13 of the MINER Act specifically directed the U.S. National Institute for Occupational Safety and Health (NIOSH) to provide for research into the effectiveness and viability of refuge alternatives for underground coal mines. This mandate culminated in the 2009 adoption of changes to Title 30 of the Code of Federal Regulations (30 CFR) mining health

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and safety regulations, requiring underground coal mines to provide mine emergency refuge alternatives and associated components, to provide a life-sustaining environment for persons trapped underground. Such refuge alternatives can be either self-contained mobile units or built-in-place facilities. The regulatory changes also include provisions establishing requirements for MSHA approval of refuge alternatives and their components, and among these provisions are numerous criteria for providing a safe breathable atmosphere under positive pressure within the refuge alternatives. One specific criterion for maintaining a safe refuge alternative atmosphere requires the inclusion of an air pressure relief valve that will activate at a maximum of 1.25 kPa (0.18 psi), or at a pressure above mine atmospheric pressure, in the refuge alternative, as specified by the manufacturer when the breathable air is supplied by a fan or compressor (MSHA, 2008).

The primary purpose of the required relief valve is to limit the maximum positive pressure within the refuge alternative to prevent damage to refuge alternative 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 refuge alternative airflow requirements based on maximum occupancy, preventing reverse airflow before positive pressure is established or if it is lost during refuge alternative use, surviving MSHA-specified overpressure and flash fire conditions prior to refuge alternative deployment, preventing an overpressure that may interfere with personnel entry and exit of the refuge alternative, and in some cases allowing necessary unobstructed airflow prior to refuge alternative deployment. If the pressure relief valve fails in the open position, contaminants from the mine could enter the refuge alternative and increase toxic gas levels inside. Failure in the closed position would prevent purging of contaminants and unsafe pressures within the refuge alternative would result.

The Pittsburgh Mining Research Division (PMRD) of NIOSH has been studying and testing the application of relief valves for refuge alternatives. Work thus far has focused primarily on the relief pressure and flow characteristics of a commercially available, purpose-built refuge alternative relief valve, as well as adaptations of four relief valve designs normally used in other applications. Two of the four adapted check valves are presently used in builtin-place refuge alternatives.

This paper details the laboratory testing and custom-built apparatus by which relief pressures have been measured and studied while controlling valve configurations, flow levels and duct characteristics.

Experimental setup

A pressure relief valve test stand was previously developed to test three pressure relief valves (Lutz et al., 2016). For the research described in the present paper, the pressure relief valve test stand was updated to include a variety of new sensors to better measure the performance of a wider variety of pressure relief valves.

The pressure relief valve test stand consists of a 1.12-kW (1.5-hp) centrifugal fan, used in a blowing configuration, that can produce a maximum pressure of 1.70 kPa (0.25 psi) at 24.9

m^3/min (880 cu ft per min), standard 10.2-cm (4.0-in.) and 12.7-cm (5.0-in.) ductwork, digital pressure gauges, an analog pressure gauge, an air velocity transducer and an airflow transducer with built-in flow straighteners, as illustrated in Fig. 1. A photograph of the test setup is shown in Fig. 2. The bleed-off leg and gate provide a means to reduce the airflow to the relief valve. The pressure gauges and airflow transducers provide the operating parameters of the relief valve under test. For each test conducted, time-history data are recorded by the data acquisition system and displayed in graphical form on the monitor. The different vertical angle configurations for pressure relief valves provide different relief pressures and flows, depending on the angle of the relief valve and resulting force required to open the relief valve. The system is modular in that duct-work can be extended or reduced and pressure relief valves can be quickly switched out.

Valve designs

Five valve designs were tested using the benchtop setup. A commercially available polyvinyl chloride (PVC) check valve with diameter of 15.2 cm (6.0 in.), which is currently in use on some MSHA-approved built-in-place refuge alternatives, was tested with no modification (Fig. 3). The flap is constructed of plastic with a rubber surround, which serves as the hinge.

A commercially available Schedule 40 PVC check valve with diameter of 10.2 cm (4 in.) (Fig. 4) was tested in its original configuration and also modified by adding weights to the valve flap to increase the relief pressure. The flap seals with an O-ring that is captured in the outer edge of the flap. Both of the PVC check valves are normally used in wastewater systems to prevent backflow.

A commercially available steel check valve (Fig. 5) that is used in an approved refuge alternative was tested with the original torsion spring and also with an alternate spring. The unit is steel-cased and has a steel flap design that is spring-loaded and sealed with an elastomer gasket.

A commercially available, purpose-built relief valve that was designed for refuge alternatives and is currently installed in production mines (Fig. 6) was also tested. The valve was tested in a configuration modified to reduce the relief pressure in an attempt to achieve a maximum opening pressure of 1.25 kPa (0.18 psi).

Finally, a brass/cast iron butterfly check valve was tested (Fig. 7). It was modified by removing the torsion springs to lower the relief pressure to 1.25 kPa (0.18 psi) and orienting the valve to use the weight of the brass parts to create relief pressure resistance. These valves are used for backflow prevention in water, oil, inert gas and fuel systems.

Measurements and analysis

The pressure relief valve test stand was used to measure the pressures and airflow for a number of configurations. Five different pressure relief valves were tested as described above. Each pressure relief valve was tested at three different airflows starting with the maximum possible using this test setup. When the maximum flow rate was below 13 m^3/min (459 scfm), only one flow rate was recorded. Some of the relief valves were more restrictive, causing the low flow rates. The static gauge pressure upstream of the relief valve was measured for each condition. The Veltron II airflow transducer (Air Monitor Corp., Santa Rosa, CA) was calibrated in 2015. The Setra pressure transducers (Setra Systems Inc., Boxborough, MA) had an accuracy of +1 percent of full scale. Airflows were verified with a Kanomax velocity transducer (Kanomax USA Inc., Andover, NJ), and static pressure was verified with a Magnehelic analog gauge (Dwyer Instruments, Michigan City, IN).

The first PVC check valve that was tested, denoted as pressure relief valve A, had a diameter of 15.2 cm (6 in.) and was installed on an MSHA-approved built-in-place refuge alternative. Figure 8 shows an example of the graphical output upon which Table 1 is based. The airflow was manually shut off after the pressure and flow rate stabilized following the test protocol, making the traces drop off at different points. The flow test results and static relief pressure results are shown in Table 1 for all of the pressure relief valves tested. Some pressure relief valves were only tested at one flow rate due to reaching the maximum relief pressure of 1.25 kPa (0.18 psi) or higher at the lowest tested flow rate of 10.6 m^3/min (30-person refuge alternative, 375 cfm minimum).

We modified an off-the-shelf PVC check valve with diameter of 10.2 cm (4 in.) by adding weights to the lightweight flapper to increase resistance to airflow, denoted as B.1, B.2 and B.3. This allowed for the relief pressure to be controlled by simply adding or removing known amounts of weight.

A steel check valve with diameter of 10.2 cm (4 in.), denoted as C.1 and C.2, with a rubber surround for sealing was also tested, and it was installed on several MSHA-approved built-in-place refuge alternatives. The original configuration had a stiff torsion spring that did not allow the flaps to open at the maximum pressure of the pressure relief valve test stand. Therefore, a lighter torsion spring — made of 302 stainless steel, with wire diameter of 0.097 cm (0.038 in.), spring outer diameter of 0.922 cm (0.363 in.) and angle of 180 degrees — was installed to allow the flaps to open under the test conditions and meet the 1.25-kPa (0.18-psi) specification.

Only one test configuration was used for the purpose-built refuge alternative 10.2-cm (4-in.) relief valve, denoted as D. The factory spring was replaced with a lighter spring — with spring constant of 0.18 kg/cm (1 ppi) — and a washer. Previous tests showed the valve would not open in the original configuration.

Two different configurations for the brass/cast-iron butterfly pressure relief valve with diameter of 11.4 cm (4.5-in.), denoted as E.1 and E.2, were tested: (1) 45 degrees with no spring return and (2) 90 degrees with no spring return. The unit was not tested at 0 degree because it would not be capable of sealing without a spring return. For the 45-degree configuration, the pressure relieved close to the limit of 1.25 kPa (0.18 psi). For the 90-degree configuration, the pressure exceeded the specification.

Discussion

The testing consisted of five different valve designs to be used for pressure relief in built-in-place refuge alternatives. Four of the units were purchased off the shelf, and some were modified — two different PVC check valves, a steel check valve and a brass/cast iron butterfly check valve — to evaluate the maximum relief pressures. A commercially available, purpose-built relief valve that was designed for steel portable refuge alternatives and are installed in a number of mines was also examined.

Of the five pressure relief valves tested, three valves achieved the 1.25 kPa (0.18 psi) limit. The purpose-built refuge alternative relief valve would not operate at the test setup maximum pressure of 1.70 kPa (0.25 psi) until a lighter spring was installed (Lutz et al., 2016). This manufacturer did demonstrate the ability to purge contaminated air with this valve installed in a portable refuge alternative. Additionally, the airflows through four of the check valves, as tested, are sufficient to meet the built-in-place refuge alternative requirement of 0.35 m^3/min (12.5 cu ft per min), per refuge alternative occupant, for refuge alternative capacities as high as 49 people (17.1 cu ft per min), and meet the specified relief pressure. The opening pressures or cracking pressures for all of the valves were within 5 percent of the ready state flow static pressures, so that factor is insignificant.

Conclusions

The purpose-built refuge alternative relief valve tested is used in steel prefabricated portable refuge alternatives and built-in-place refuge alternatives. As delivered, the purpose-built refuge alternative relief valve did not meet the 1.25 kPa (0.18 psi) limit. However, the valves may be calibrated to meet the specifications set by the manufacturer.

The two PVC check valves described here offer viable solutions for relief valves in refuge alternatives based on the 1.25 kPa (0.18 psi) relief pressure requirement, with one valve currently installed on MSHA-approved built-in-place refuge alternatives. The steel check valve is a viable alternative with a torsion spring change. The size of the relief valve can be chosen to allow sufficient airflow out of the refuge alternative 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 and steel check valves with further modifications (reducing the mass of the brass components, using a different torsion spring). The PVC check valve housings and flaps may need to be redesigned in order to withstand the mine atmosphere and a potential catastrophic event.

Ultimately, all of the valves may be modified to meet the pressure relief specification or achieve pressure reliefs specified by the manufacturer. It is important to note that the purpose of the testing conducted in this paper was to investigate the airflow and pressure relief characteristics of the aforementioned pressure relief valves. These evaluations do not include testing to an impulse overpressure of 103 kPa (15 psi) as specified in 30 CFR.

The pressure relief valve is a critical component of refuge alternatives. Failure may mean infiltration of hazardous contaminants into the refuge alternative following a catastrophe in the mine or hazardous pressure to the miners inside the refuge alternative when the air supply is operating. Impulse overpressure testing and modification of pressure relief valves in conjunction with blast valves may be necessary to evaluate overall survivability. This research will aid in the design of built-in-place refuge alternatives with respect to maintaining a comfortable and survivable environment inside following a disaster.

Acknowledgments

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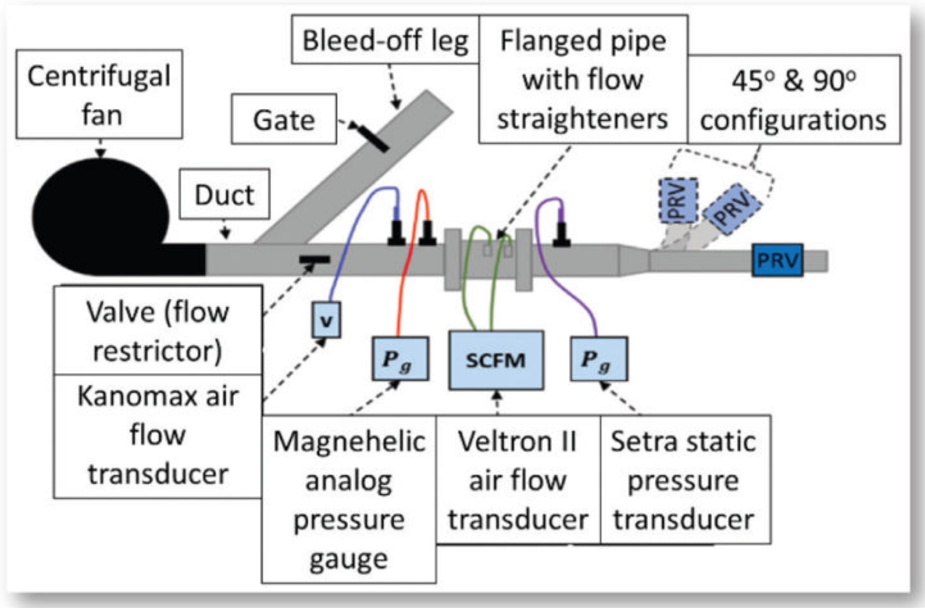

Figure 1.
Pressure relief valve test stand layout (side view).

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Figure 2.
Pressure relief valve test stand (photograph).

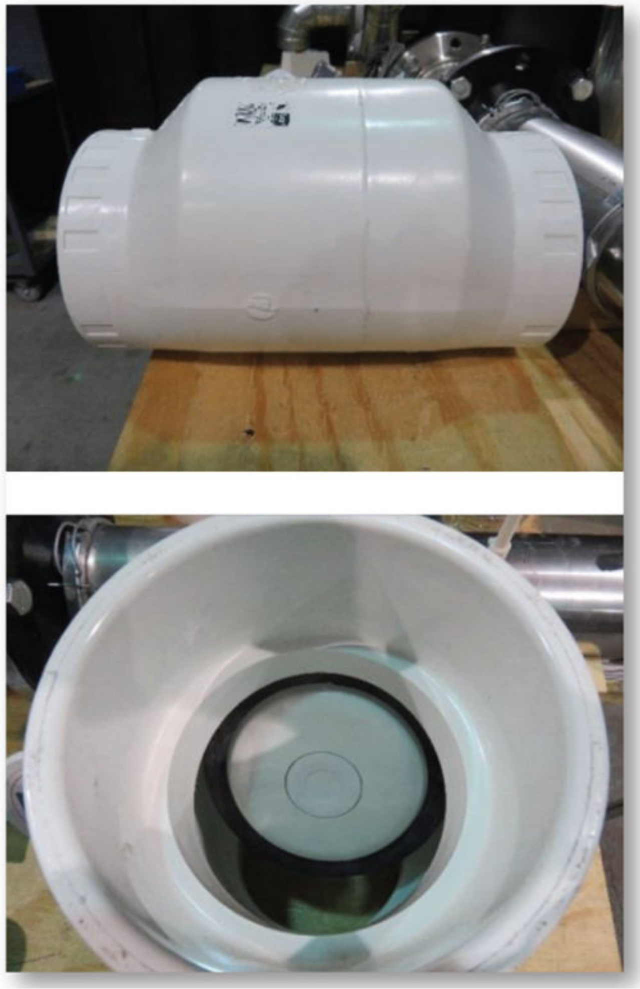

Figure 3.
PVC check valve, with diameter of 15.2 cm (6.0 in.).

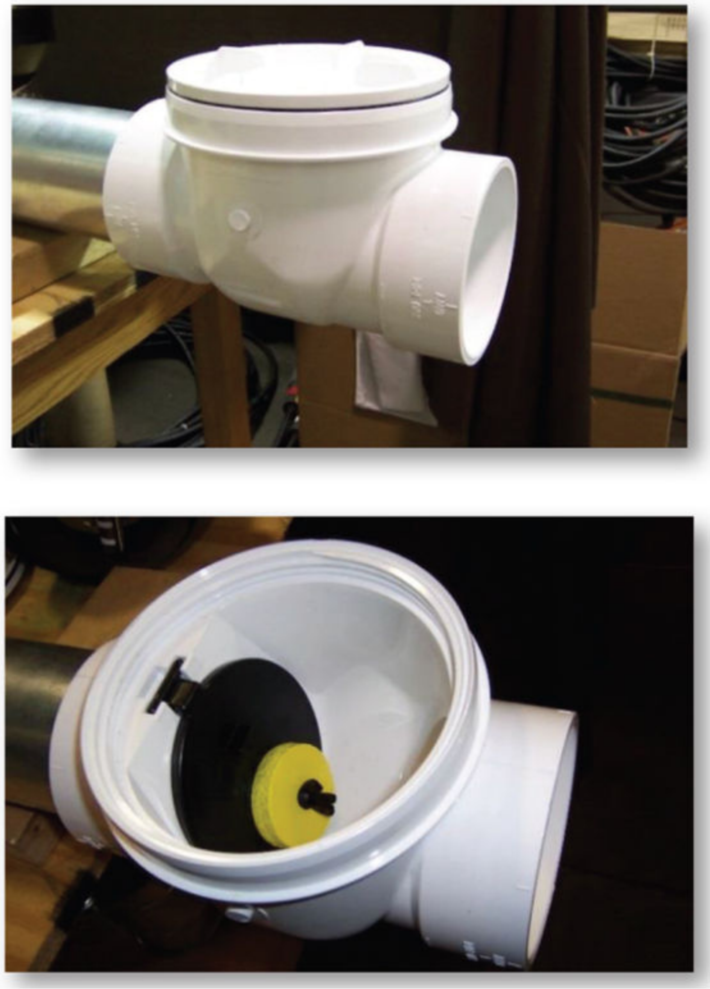

Figure 4.
PVC check valve, with diameter of 10.2 cm (4.0 in.).

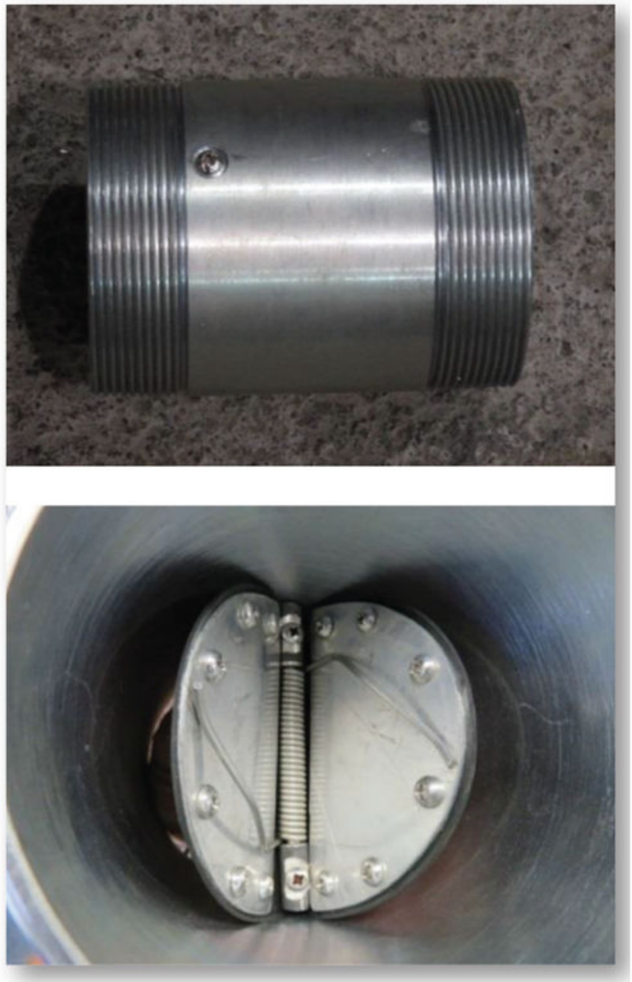

Figure 5.
Steel check valve, with diameter of 10.2 cm (4.0 in.).

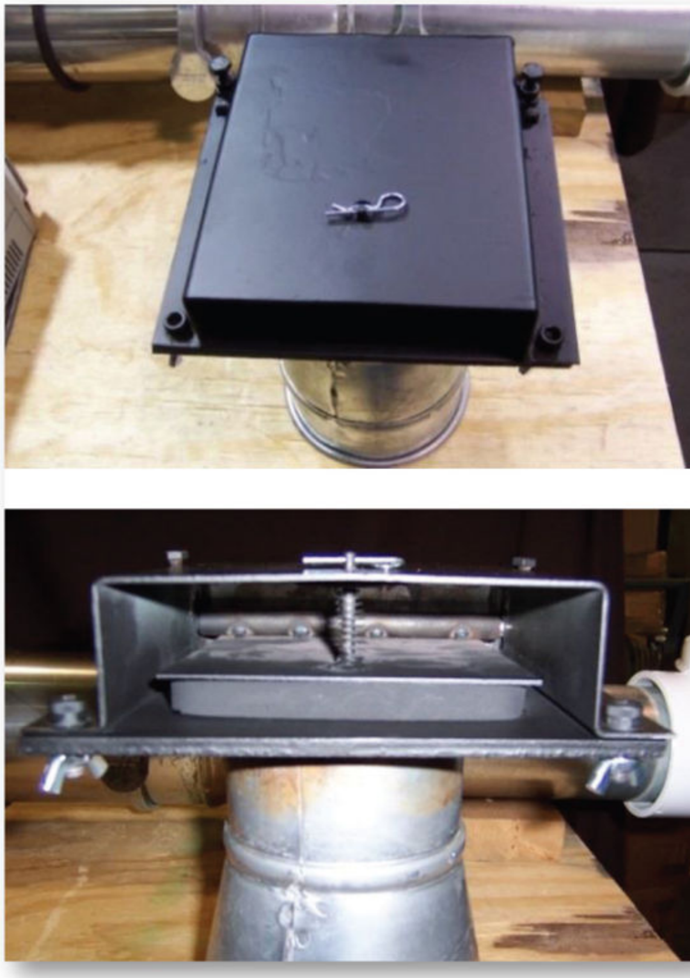

Figure 6.
Purpose-built refuge alternative relief valve, with diameter of 10.2 cm (4.0 in.).

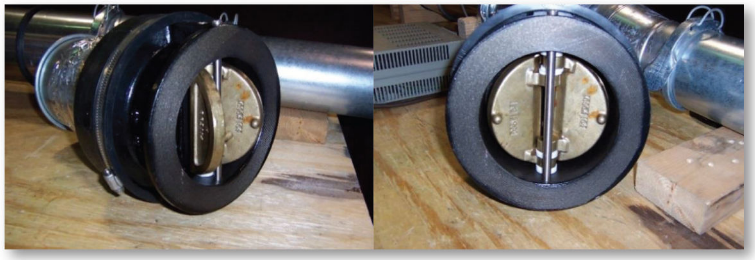

Figure 7.
Brass/cast iron butterfly check valve, with diameter of 11.4 cm (4.5 in.).

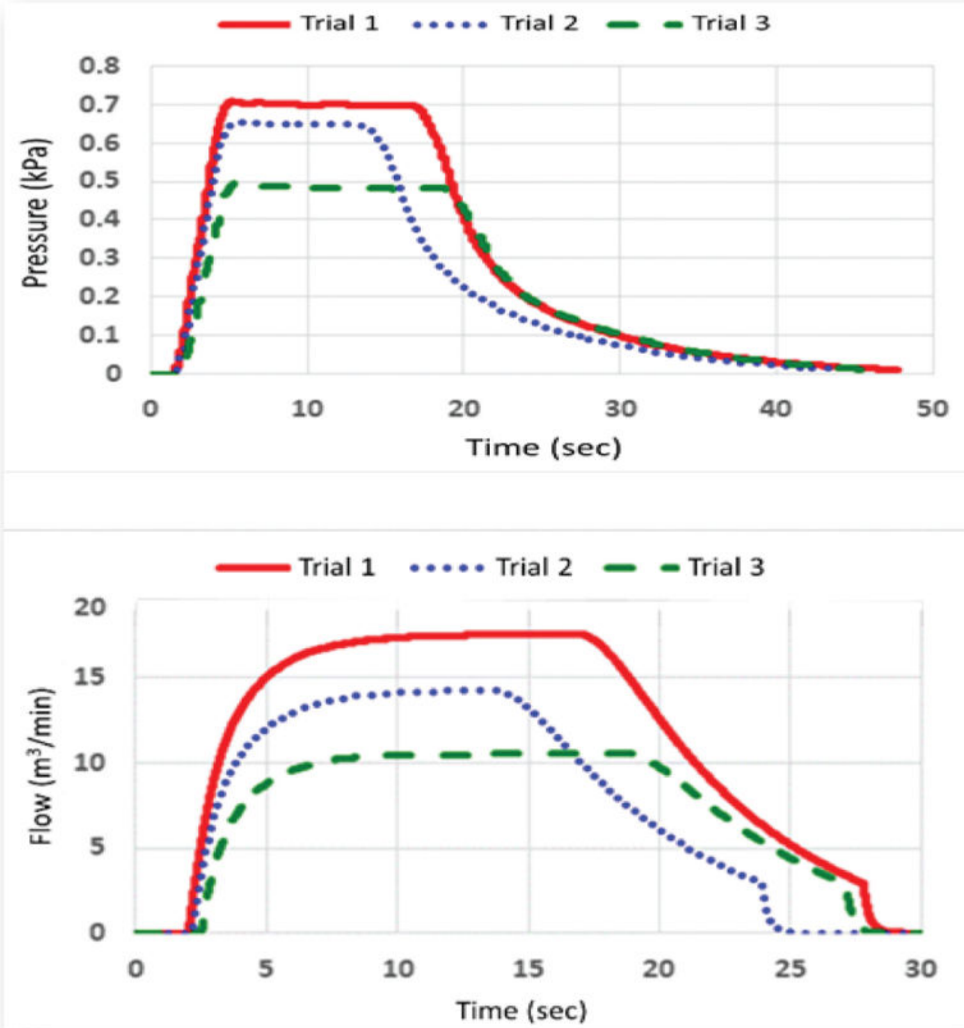

Figure 8.

Graphical results showing examples of airflow and static pressure for pressure relief valve A in Table 1.

Table 1

Airflow and static pressure test results (Q = airflow rate, P = static relief pressure).

Pressure relief valve	Valve material and type, diameter, configuration	Trial 1		Trial 2		Trial 3	
		Q (m^3/min)	P (kPa)	Q (m^3/min)	P (kPa)	Q (m^3/min)	P (kPa)
A	PVC check valve, 15.2 cm (6 in.), no modification	17.8	0.70	14.4	0.65	10.7	0.50
B.1	PVC check valve, 10.2 cm (4 in.), no weight	19.3	0.45	14.3	0.32	10.7	0.20
B.2	PVC check valve, 10.2 cm (4 in.), one weight, 0.43 kg	18.2	0.60	14.3	0.50	10.6	0.35
B.3	PVC check valve, 10.2 cm (4 in.), two weights, 0.87 kg	17.1	0.75	14.1	0.67	10.8	0.55
C.1	Steel check valve, 10.2 cm (4 in.), original spring	0.0	1.70	-	-	-	-
C.2	Steel check valve, 10.2 cm (4 in.), modified spring	15.8	1.02	15.7	1.02	10.4	0.87
D	Purpose-built refuge alternative relief valve, 10.2 cm (4 in.), modified spring	10.2	1.52	-	-	-	-
E.1	Brass/cast iron butterfly check valve, 11.4 cm (4.5 in.), no spring, 45°	12.6	1.27	-	-	-	-
E.2	Brass/cast iron butterfly check valve, 11.4 cm (4.5 in.), no spring, 90°	11.7	1.37	-	-	-	-