International Journal of Advancements in Mechanical and Aeronautical Engineering – IJAMAE
Volume 1 : Issue 4 [ISSN 2372 –4153]
Publication Date : 27 December, 2014

Flow Study and Design Analysis of a Safety Valve-Vent Pipe

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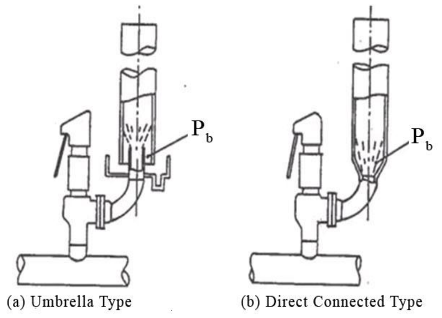
***Abstract*— Discharge of a large volume of steam from a boiler to atmosphere is a complicated and risky task. It can cause damage to equipment or even injury to personnel in the vicinity. A device was designed, based on the arrangement of a valve and vent pipe junction, such that no excessive load arising from the thermal expansion or reaction induced movement is transmitted back to the valve discharge branch, thus avoiding valve malfunction. Specimens were designed and fabricated to satisfy the actual working conditions. Both air and steam were used in the experimental works. Theoretical and experimental results were then studied on the flow phenomenon of the connection. This study leads to a design analysis of the safety valve-vent pipe. The results have shown good correlations between the theoretical and experimental results and thus lead to the prediction of valve-vent pipe sizing.**

***Keywords*— design, fluid mechanics, process control, product design, safety.**

I. Introduction

A steam boiler with very high flow rate, high pressure and temperature must be fitted with proper safety valve. The large volume released through a steam safety valve in a power plant has to be discharged to the atmosphere harmlessly (Sumathipala, Venart, & Steward, 1990). Safety relief valves play an important role in industrial emergency pressurized systems to ensure the operating pressure does not exceed the allowable designed limit. Two types of arrangements have been adapted in most of the relief valve-vent pipe system in the steam power plant, as seen in Figure 1, an umbrella type and a direct connected type.



(a) Umbrella Type (b) Direct Connected Type

Figure 1. Schematic diagram of typical arrangements of safety relief valve vent pipe (Liao, 1974).

The umbrella type was first investigated almost seventy years ago by (Benjamin, 1941, 1943), however many trial and error method was applied in the calculation of a vent size. Such piping could be designed with more confidence if a rational basis were employed (Leung, 1986; Liao, 1974), and later (Leung, 2004) introduced a detailed theory on the discharged coefficient for the safety relief valve (SRV), comparing fundamental and modified theories. The theoretical analysis would yield to two-phase discharge coefficient as a function of the omega parameter, where omega can be summarized to various nature of the compressible discharge fluid. Earlier, the two-phase flows through SRV and pipes were compared on the calculated results using the TPHEM, CCFLOW and RRERSP computer programs, (Adair & Fisher, 1999). These studies found that for most low-to-moderate viscosity flow and the frozen flow, the results from the various programs agreed between each other, despite differences in their calculation methods. The TPHEM program was found to produce better results for high viscosity flows through SRV (nozzle) and for pipe down flows. The second method, a direct connection was developed within the industry (Brandmaier, 1982; Campbell, Longhurst, & Moriarty, 1985), with more recent studies by Schmidt (Schmidt, 2012), Moncalvo & Friedel (Moncalvo & Friedel, 2006) and Dasgupta & Karmakar (Dasgupta & Karmakar, 2002).

Dasgupta & Karmakar (Dasgupta & Karmakar, 2002) used modelling and simulation to examine the safety valve of modern design, and they have shown that the section from inlet to the seat of the valve can be formed to act as a nozzle. Consequently, with direct connection the overall “nozzle efficiency” from the inlet to outlet of such a valve must be low. The nozzle efficiency was used to determine the steam velocity at the valve pipe outlet, thus a correct sizing of safety

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valve should be chosen to ensure a safe relief when the valve is operating beyond the normal condition. Schmidt (Schmidt, 2012) studied on a relief of two-phase gas/liquid mixture according to method recommended in the ISO4126 part-10, which leads to significantly smaller relief areas compared to the API 520. For multi-purpose plants with available safety devices this method allows for a considerable expansion of the application range of reactors. Moncalvo & Friedel (Moncalvo & Friedel, 2006) had worked on valves with a high and low value of the related lift with a valve nozzle orifice according to American Petroleum Institute (API) RP 526, and they managed to produce mapping of viscosity effects for selected poly-liquids on the liquid flow with correlation to Reynolds number, viscosity correction factor and discharge coefficient of the valves. The results obtained do not prove that the use of either the iterative procedure following EN ISO 4126-4 or the direct industrial method leads to an over-sizing for a postulated worst credible mal-operation case (Moncalvo & Friedel, 2006). They had generalized that no difference occurs when sizing the viscous flow relief areas for valves with high or low related lift. They consequently suggested for the larger relief area, which agreed with the study by Morris (Morris, 1996). Morris had studied on the true discharge coefficient for liquid flow through a safety valve, with the orifice-to-inlet diameter ratio. The outlet nozzle on the vessel should have a diameter larger than the valve inlet diameter in order to satisfy the stability criterion.

Based on the above phenomenon and behaviors, a valve-vent pipe safety relief valve was introduced in this study. Theoretical and experimental investigations were carried out on the induction and blowback characteristics at the valve-vent joint. Assuming sonic flow at the vent pipe outlet, the static pressure at the vent pipe inlet is calculated considering friction losses in a long pipe. Blow-back is assumed not to occur if the velocity head of the steam jet leaving the valve pipe is equal to or greater than the calculated static pressure inside the vent pipe inlet.

Certified pressure relief valves (BS6759, 1984) may be used to prevent pneumatic explosion of a pressurized system. An allowable back pressure was studied by Francis &Betts (Francis & Betts, 1998) and tests were performed on a valve designed to compensate for backpressure and flow characteristics. The critical backpressure ratio for choked compressible flow was identified. An interesting phenomenon was observed in the experiment, where a shockwave exists beneath the disc of a skirted safety valve, and that it was attached to the underside of the disc, rather than the skirt. The shock wave affected the lifting force on the disc.

An investigation would be required for the influence of area ratios on the sudden enlargements at the nozzle, the valve pipe exits and the lengths (and hence resistance) of the valve and vent pipes. This is to determine the state of the flow at various positions in the systems as the supply pressure was varied. The important parameter is the pressure in the separated region at the open junction between the valve and vent pipes (Brandmaier & Knebel, 1976; Durst, Pereira, & Tropea, 1993; Sale, 1979).

This paper documents an investigation to obtain data which could be used in the rational design procedure for vent pipes, to ensure that blow-back will not occur. Tests were conducted to investigate the effects of base pressure on various variables.

II. Experimental Test Facility

To investigate the factors affecting flow in the vent pipe system it was decided to perform tests using both air and steam as the flowing fluids and to use small scale model tests. The air test rig received supply pressure up to 18 bars and the steam test rig in which dry saturated steam from a boiler passed to the test specimen up to 8 bars. The test specimen acting as a small scale model for the safety valve-vent pipes are as follows:

A. *Nozzle*

A brass 6 mm diameter convergent nozzle was used in all tests relating to the investigation of base pressure and the flow in nozzle-valve pipe-vent pipe arrangements.

B. *Valve Pipes*

Three different bore diameter valve pipes were used each having the same length/diameter ratio (*L/D*) of 5 and connected a 6mm diameter nozzle. The cross-sectional area ratios are shown in Table 1.

TABLE I. VALVE PIPES CROSS-SECTIONAL AREA RATIOS

Valve Pipe	Bore Diameter	Area Ratio, A_r
A	7.5 mm	1.56
B	8.5 mm	2.01
C	10.0 mm	2.78

Extension “valve pipes” of 8.5mm diameter having $L/D = 5.88$ were fitted to part “B” in Table 1, depending on the required length.

C. *Vent Pipes*

Four different bore diameter vent pipes each of which have equal length/diameter ratio, $L/D = 5$, were used. These were for connection to the valve pipe of bore diameter 8.5mm, as seen in Figure 2. The vent pipe connected to the 8.5mm diameter valve pipe have cross-sectional area ratios as shown in Table 2.

TABLE II. VENT PIPES CROSS-SECTIONAL AREA RATIOS

Vent Pipe	**Bore Diameter**	**Area Ratio, A_r**
V	10.8 mm	1.61
W	12.3 mm	2.09
X	16.4 mm	3.72
Y	20.2 mm	5.65

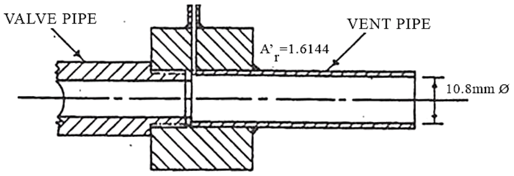


Figure 2. Valve vent pipes connections.

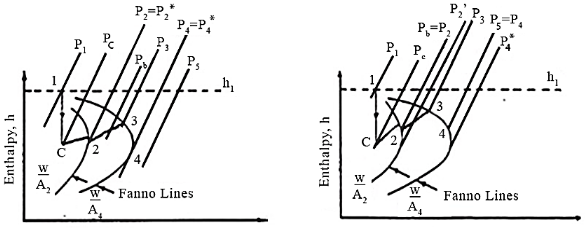
III. Theoretical Consideration

The consideration was based on two parts, the first concerns the steam flow through safety valve vent pipes and the second concerns the base pressure at a sudden enlargement with initially sonic or supersonic flow.

A. *Safety Valve Vent Pipe Steam Flow*

There are two important factors in the design of safety valve vent pipe. First, the vent must have sufficient capacity to carry away all the steam passed by the valve. Second, the vent line must be so constructed that the thermal expansion, which accompanies the passage of steam, will not include stresses into the valve or its connection to the protected vessel. The clearance between valve and vent pipe insures that forces on the vent pipe are not transmitted to the valve pipe. Calculation of the static pressure at the inlet to the vent is only part of the problem. The other part is to determine whether steam will blow back. In order to avoid blow-back the dynamic pressure of the steam jet must be equal to or greater than the calculated static pressure inside the vent pipe.

The analysis is based on the theory of compressible fluid flow under irreversible adiabatic conditions to establish a method and criterion for vent stack design (Durst, et al., 1993). The method developed is applicable to both choking and non-choking conditions at the valve exit and vent stack outlet, which can be seen from process diagrams explained by enthalpy-entropy diagram in Figure 3.



(a) Choking at valve exit and pipe outlet

(b) Non-Choking at Valve exit and pipe outlet

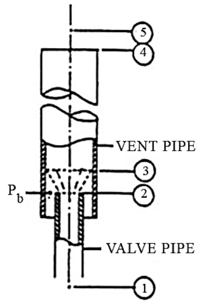


Figure 3. Valve vent pipe process diagram(Liao, 1974).

The validity in the application of perfect gas equations is applied to superheated steam (Durst, et al., 1993; Liao, 1974; Mayinger, 1988), but less so for saturated steam. An analysis of flashing (evaporation) and non-flashing water flows through a safety relief valve was also studied by Bole, et al (Bolle, Downar-Zapolski, Franco, & Seynhaeve, 1995). The analysis was based on the pressure distributions inside the valve, the inlet and outlet temperatures and the mass-flow rate, and with the characteristics of the valve giving the mass-flow rate as a function of the square root of the pressure drop. The experimental results on hot pressurized water are compared with equilibrium and relaxation two-phase flow models. The results of the non-equilibrium character of fast evaporation and its substantial influence on the two-phase flow behavior are demonstrated. A more accurate analysis should consider the differences between the properties of the primary and secondary fluids, i.e. steam and air.

B. *Base Pressure at Sudden Flow Enlargement through Nozzle-Valve Pipe-Vent Pipe System*

Flow is assumed to be steady, adiabatic and one-dimensional. Two Fanno curves can be plotted on a temperature-entropy diagram, one for flow through the valve pipe and the other for flow through the vent pipe. The relative location of the Fanno curves depends on the areas of the pipes. Figure 4 is a sketch of such a diagram.

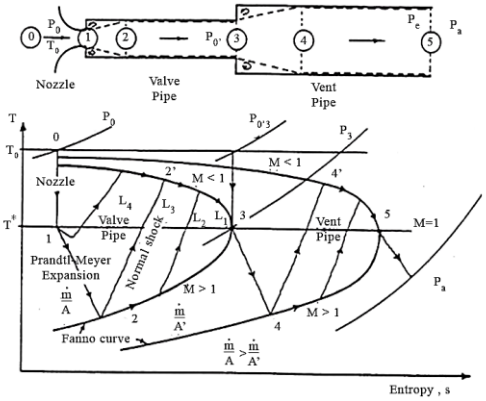


Figure 4. T-S diagram for one-dimensional flow with friction through nozzle-valve pipe-vent pipe system.

For a short length of valve pipe the sonic flow at nozzle exit expands into the valve pipe and supersonic flow is established (started flow) in the valve pipe. As the flow passes along the valve pipe the Mach number decreases and may be greater than unity at valve pipe outlet. If the valve pipe length is greater than a certain value then Mach number will be unity at outlet and a normal shock wave would occur at some place within the valve pipe. For all valve pipe lengths greater than this particular value the Mach number at outlet is equal to 1. It is often the case that the vent pipe system is designed that M = 1 at valve pipe outlet. This gives the lowest value of total-head pressure possible at valve pipe outlet. For this to be so all that is required is that the valve pipe length be greater than a certain minimum value. The minimum length can be estimated by assuming isentropic flow from the nozzle outlet to the valve pipe area to give the inlet Mach Number and then use the analysis for flow in a constant area duct with friction to find the length L^* based on a friction coefficient given in (1).

$$-C_f\frac{4}{d}(L-L^*)=\frac{1}{\gamma}\cdot\frac{(1-M)^2}{M^2}+\frac{\gamma+1}{2\gamma}\ln\left[\frac{\frac{1}{2}(\gamma+1)M^2}{1+\frac{1}{2}(\gamma+1)M^2}\right] \tag{1}$$

Where C_f is the coefficient of friction, d is the diameter, L is the length, γ is the ratio of specific heats and M is the Mach number.

Various process paths within the valve pipe are indicated in Figure 4 for $L_1<L_2<L_3<L_4$. The figure also shows process paths for flow in the vent pipe. The minimum possible base pressure occurs when the flow at the inlet of the vent pipe is supersonic (started flow). The minimum value of base pressure can be obtained with any length of vent pipe which just allows supersonic flow to be established (corresponding) to 3-4-4'-5 in Figure 4. The minimum length can be estimated if the Mach number at 4 is known. With just a vent pipe inlet a normal shock causes the pressure to increase and makes the downstream flow at 4' to be subsonic. Similarly, the maximum length for this condition can also be estimated.

The analysis on the pressure wave propagation in pipes based on the fast transient transfer from steam to two-phase flow had been carried out by Nagel (Nagel, 1986), which successfully showed a good agreement with experimental data.

IV. Experimental Work and Analysis

The experimental works were performed both by using air and steam, but most of the critical measurements have to be carried out using air as a working fluid. The results were used to verify the design procedure of the vent pipe system.

A. *Measurement of Base Pressure with Various Area Ratios and Varying Head Supply Pressure.*

A 6 mm diameter nozzle was used together with various valve pipes in this test. Three different area ratio of valve pipes were used i.e. A_r = 1.56, 2.01 and 2.78, all with the length to diameter ratio of five.

Extension pieces, each with L/D = 5.88, could be connected to the L/D = 5 valve pipe of A_r = 2.01, to make up various length to diameter ratio (L/D). Valve pipes with L/D = 10.88, 16.76, 22.65 and 28.53, were tested to determine the variation of base pressure P_b and exit pressure P_e with total head pressure P_o. The total head supply pressure P_o was gradually increased and for each setting the base and exit pressures were measured. This enables the careful location of the transition from unstarted to started flow. The definition of unstarted and started flow has been explained in detail by Martin and Mukerjee (Martin & Mukerjee, 1968), Kost (Korst & Page, 1956) and Nash (Nash, 1963).

Results from this test are shown in Figure 5. It is apparent that the base pressure ratio P_b/P_a against P_o/P_a decreases nonlinearly, reaches a minimum value and then increases almost linearly in direct proportion with increasing P_o/P_a , Figure 5(a). The linear portion of the graphs implies that P_b/P_o remains constant above a certain value of P_o/P_a , see Figure 5(b).

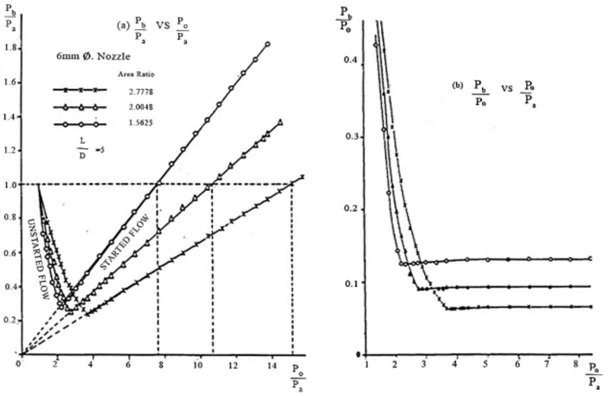


Figure 5. Valve pipe back pressure of different area ratio against supply pressure.

The value of P_b/P_o is constant and the range of P_o/P_a over which it applies is dependent on the area ratio. Larger area ratio results in lower minimum possible value of P_b/P_o. At this point it is interesting to note that if the connection between the nozzle and the valve pipe had been open to the atmosphere, the value of overall pressure ratio P_o/P_a at which the base pressure equals to atmospheric pressure, i.e. $P_b = P_a$, see dotted line of Figure 5(a), increases as the area ratio increases. Table 3 shows the relationship between area ratio and pressure ratio, P_o/P_a .

TABLE III. RELATIONSHIP AREA RATIO AND P_o/P_a WHEN $P_b=P_a$

Area Ratio	**1.56**	**2.01**	**2.78**
P_o/P_a	7.6	10.6	15.0

If P_o/P_a is greater than the values listed above then blow-back would occur at the open connection between nozzle and valve pipe. The different between started and unstarted flow become apparent in Figure 5(b). P_b/P_o is constant and equal to the minimum value for the flow said to be as 'started'.

B. *Measurement of Base and Exit Pressure with Various Valve Pipe Lengths and a Single Area Ratio*

In this test four different length of valve pipe were used, L/D = 10.88, 16.76, 22.65 and 28.53, for cases where the area ratio was 2.01. The intention of this test was to investigate the influence of vent pipe length and the resulting frictional pressure drops on the flow in the expansion region.

The results plotted in Figure 6 show that for the unstarted flow the values of P_b/P_a at a particular value of P_o/P_a are somewhat different from each other. This effect is undoubtedly due to friction within the valve pipe causing the pressure just downstream of the re-attachment position, as seen in reference (Nash, 1963), to be greater than P_a. Once the flow has become started for the cases with L/D = 10.88 and 16.78 (and also from the previous result of L/D = 5), then its base pressures are identical. For the other two longer L/D values, i.e. 22.65 and 28.53 the P_b/P_a values are higher.

Examining the variation of P_e/P_a it is seen that for all cases the exit pressure equals the atmospheric pressure until a particular value of P_o/P_a is reached, see Figure 6. The valve pipes exit pressure, P_e, being equal to the atmospheric pressure, P_a, indicates that the flow at valve pipe outlet is subsonic. If $P_e>P_a$ the flow is supersonic and if $P_e<P_a$ a normal shock wave occurred at the exit.

The variation of P_e/P_a for L/D = 10.88 indicates a sudden drop in exit pressure for only a small increase of supply pressure. This is due to formation of shock wave which moves from upstream to downstream of the pressure tapping point. The Mach number at the valve pipe exit, M_e, can be estimated from the graph of Figure 6 and the correction as in (2). (Taken γ = 1.33 for steam and γ = 1.4 for air).

$$\frac{P_b}{P_o} = \frac{A_r \frac{P_e}{P_o}(1+\gamma M_e^2)}{(A_r - 1)} - \frac{0.528\left|1+\gamma\left\{1-3.11\left(1-C_d^{\frac{1}{2}}\right)\right\}\right|}{(A_r - 1)} \tag{2}$$

Where P_a is the pressure at atmospheric condition, M_e is the Mach number at exit condition and C_d is the coefficient of discharge.

For the case with L/D = 16.76, the shock wave is undetectable from the graph in Figure 6, which indicates that the increased friction has reduced the Mach number to almost unity at the valve pipe exit

For the larger values of L/D, i.e. 22.65 and 28.53, the exit pressure stays at the atmosphere value until P_o/P_b becomes approximately 3.9, after which it increases. The P_o/P_b values for these lengths indicate that the flow in the valve pipe was unstarted, i.e. subsonic, and because $P_e>P_a$, this implies that the Mach number is equal to unity at the valve pipe outlet. If the flow, for a particular value of P_o was started (as with L/D = 5, 10.88 and 16.76) and if the length was then increased to given L/D greater than 17, then this length would be such that the additional frictional would make the flow become unstarted with choking (M = 1) occurring at the exit.

For the area ratio being considered and with M = 1 at both nozzle and valve pipe outlets, using the graph of Figure 6 and Equation (2) gives P_e/P_a=0.2631 P_o/P_a, which is shown by the dashed line in Figure 6.The agreement is excellent considering that no allowance has been made for the boundary layer at nozzle exit and the velocity profile at valve pipe outlet will not be one-dimensional.

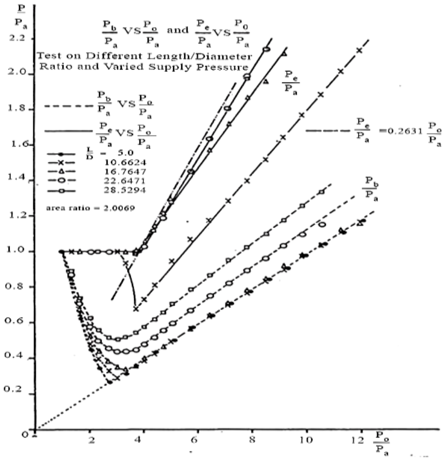


Figure 6. Valve pipe back and exit pressure of different length diameter ratio against supply pressure.

These results clearly show that if the valve pipe is made longer than a certain minimum length, as long as the total-head pressure is greater than certain value the flow at the valve pipe exit will be sonic flow. This flow behaviour can be seen in Figure 4.

C. *Measurement of Base Pressure at the Valve Pipe-Vent Pipe Junction with the Valve Pipe Flow Choked at Exit*

The previous tests have shown that choking occurred at exit of *L/D* = 22.65 and 28.53 valve pipes. The same procedures were repeated but in this test the vent pipe was connected to the valve pipe as shown in Figure 2. For every test, each of the vent pipes was connected to the *L/D* = 28.53 valve pipe of 8.5 mm diameter.

Experiments were conducted to establish whether the two-dimensional nature of the flow at a choked valve pipe exit has an effect on the subsequent flow in the vent pipe. The results were compared to the previous set of experiments, and shown in Figure 7. Similar to characteristics in Figure 6, the agreement between the results for flow from the nozzle and from the choked valve pipe are excellent. Thus data obtained using a sonic nozzle and a short valve pipe can be used to predict the base pressure which would be obtained for flow from a choked valve pipe. This is of great importance when dealing with the design of vent pipe system.

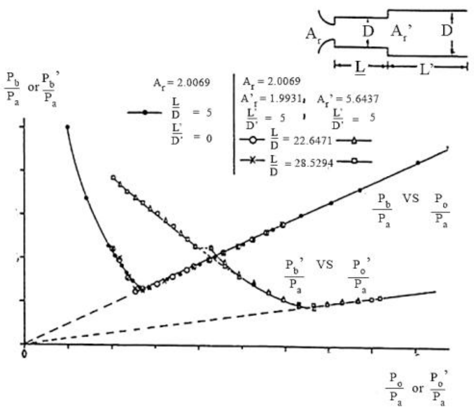


Figure 7. Base pressure at valve pipe-vent pipe junction.

V. Vent Pipe Design

The design is based on the experimental results discussed previously. The base pressure between the valve pipe and vent pipe must not be permitted to exceed atmospheric pressure. The maximum allowable length of vent pipe to avoid blow-back is based on the experimental results with choked flow at the exit of the valve pipe, for various area ratios and $L'/D' = 5$. The experimental results can be seen in Figure 8. Experimental results suggest that the best valve pipe size for the design procedure is 8.5 mm bore diameter and area ratio, $A_r = 2.01$, relative to the 6.0 mm nozzle throat. The length to diameter ratio for valve pipe is $L/D = 28.53$. The sizes of the vent pipe chosen were 10.8, 12.3, 16.4 and 20.2 mm bore diameters with the area ratio relative to the 8.5 mm diameter valve pipe, $A'_r = 1.61$, 2.09, 3.72 and 5.65, respectively.

For the four different diameters of $L'/D' = 5$ vent pipes, the smallest diameter 10.8 mm of $A'_r = 1.61$ gives base pressure ratio $(P'_b/P'_o)_{\text{minimum}} = 0.15$ and the biggest diameter 20.2 mm of $A'_r = 5.65$, gives $(P'_b/P'_o)_{\text{minimum}} = 0.045$. These values are obtained from Figure 8.

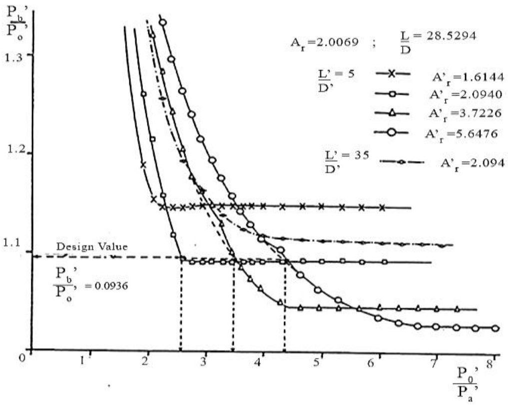


Figure 8. Vent pipe back pressure of different area ratio.

The ambient pressure for the designed vent pipe system was assumed to be 10 psi (abs.). If the supply pressure was set about 200 psi (gauge) or 14.79 bars (abs.), allowed to blow through the nozzle with valve pipe area ratio of 2.01, as seen Figure 9, the calculated maximum permissible value of P'_b/P'_o is 0.0936. Calculated P'_b/P'_o is seen to lie between the maximum and minimum value corresponding to the vent pipes having area ratio of 1.61 and 5.65, see Figure 8. The vent pipe with $A'_r = 1.61$ is always under a situation of blow-back since (P'_b/P'_o) is above the maximum permissible value. For other area ratios of $A'_r = 2.09$, 3.72 and 5.65 flow will be unstarted, therefore only three of these area ratios need to be investigated to avoid blow-back. Looking at the vent pipe $A'_r = 2.09$, the result for $L'/D' = 35$ shows that blow-back had occurred, which can be proved theoretically through Equation (1). The critical length was found to occur at $L'/D' = 28.12$, which is less than the value used in the test, thus blow-back was expected.

The critical length for the above vent pipe area ratios can be predicted theoretically and the results are shown in Table 4.

TABLE IV. LENGTH TO BE ADDED TO $L'/D' = 5$ VENT PIPE

Diameter, D'	**10.8mm**	**12.3mm**	**16.4mm**	**20.2mm**
Area ratio, A'_r	1.61	2.09	3.72	5.65
$P'_o/P_a = P'_o/P'_e$	Always blow back	2.55	3.45	4.35
$M'e$		0.67	0.52	0.44
$\frac{C_f 4 \mid L-L^* \mid}{D'}$		0.27	0.92	1.72
$\therefore \frac{\mid L-L^* \mid}{D'} = \frac{L''}{D''}$		23.12	73.78	130.86
i.e. L'', for $D' = D''$		285mm	1212mm	2642mm

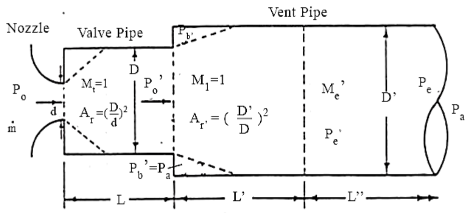


Figure 9. The schematic diagram of the vent pipe.

Vent pipes were made according to the above design, shown in Figure 9. It was tested at total-head supply pressure of 200 psi (gauge). The base pressure was measured and the results are presented in Table 5. It can be seen that errors in all the cases are small, thus the design is reasonable.

TABLE V. BASE PRESSURE, P'_b MEASURED RESULTS

Area Ratio, A'_r	**2.094**	**3.7226**	**5.6476**
Extended Length/ diameter ratio, *L''/D''*	23.12	73.78	130.86
Measured results for P'_b, psi (abs.)	10.05	9.2585	9.8774
Error	+0.5%	-7.4%	-1.2%

VI. Observation and Discussion

The presented results indicate that bigger vent area ratio, A'_r will require longer maximum permissible length, L' of the vent pipe. It is apparent that as the valve pipe area ratio increases, the total-head supply pressure into the vent pipe, P'_o will decrease, as seen in Figure 10.

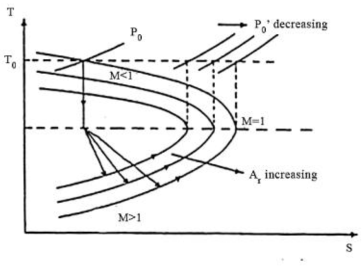


Figure 10. *T-S* diagram for flow into the vent pipe.

Referring to Figure 11, the theoretical values for the unstarted case (neglecting boundary layer) were plotted along with the experimental results for each area ratio. A certain value of the design ratio (P'_b/P'_o) fixes the value of (P'_o/P'_a), for the unstarted case only. Comparing the theoretical and experimental it is apparent that it follow (3).

$$\left(\frac{P'_o}{P'_a}\right)_{experimental} > \left(\frac{P'_o}{P'_a}\right)_{theoretical} \tag{3}$$

Thus, if the maximum length of the vent pipe is obtained using the theoretical values, the effects will be as follows:

P'_e will become greater thus decreasing M'_e, and the exit temperature T'_e will increase, therefore the viscosity will be increased and this will affect the Reynold's number and from the Blasius equation, the coefficient of friction, C_f will increase. The exit Mach number M'_e is decreased when the value of $C_f 4|L-L^*|/D'$ is increased. The effect of increasing C_f is very small, thus $|L-L^*|/D'$ is increased. Therefore, the critical length L^* obtained using theoretical unstarted flow values will be greater than the length which actually causes the blow-back.

For lengths of vent pipe area ratio greater than that shown in Figure 12, the desired value of $(P'_b/P'_o)_{\text{minimum}}$ must be used. Furthermore longer pipe will require greater area ratio, as seen in Figure 8. Figure 12 presents the results obtained from many tests using air and steam. It is apparent that the trend for air and steam is similar. However steam has higher minimum permissible back pressure for a given area ratio (Boccardi, Bubbico, Celata, & Mazzarotta, 2005).

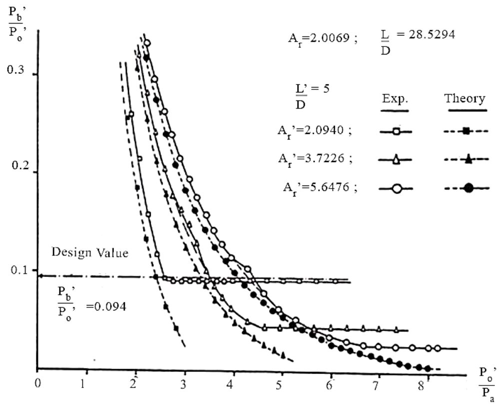


Figure 11. Comparison between experimental and theoretical of (P'_b/P_o) against (P'_o/P_a).

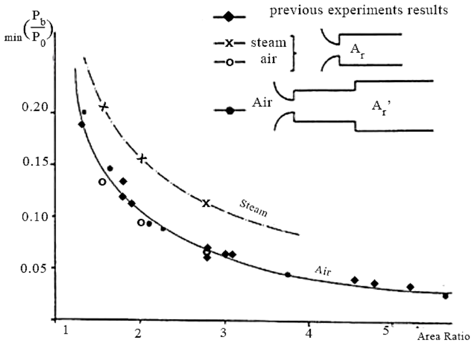


Figure 12. Relationship between minimum permissible back pressure against Vent Pipe area ratio.

VII. Conclusion

This paper presents an investigation of the base pressure at the connection between the valve and the vent pipe. To ensure that no blow-back occurs at the clearance between the valve pipe and the vent pipe, the base pressure must be equal or less than the atmospheric pressure. The length of the vent pipe and its diameter obviously affects the base pressure. Smaller diameter or longer length of the vent pipe will result in higher base pressure and hence a greater possibility of blow-back.

The presented one-dimensional theoretical analysis is incapable of predicting the condition when the flow changes from unstarted to started. The minimum base pressure ratio occurs when flow is started. No analysis is available which will predict the minimum base pressure ratio for the case of sonic flow expanding into a larger area duct. For this reason experiments were conducted for both air and steam flow, to obtain an empirical relationship between the geometry and the minimum base pressure ratio. The empirical data was used in the design of vent pipes.

Acknowledgment

The authors would like to thank UTM-Imperial Centre for Low Carbon Transportation Research Alliance, Universiti Teknologi Malaysia (UTM), for providing the research facilities.This research work has been supports by UTM Research University Grant (Vot 01G51), Ministry of Science and Technology Malaysia and the Ministry of Higher Education Malaysia.

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