

## USER GUIDE

# Discharge of a Pressure Vessel Web Application

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21 September 2020

Atkinson Science welcomes your comments on this User Guide. Please send an email to [keith.atkinson@atkinsonscience.co.uk](mailto:keith.atkinson@atkinsonscience.co.uk).



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## 1 Introduction

The Discharge of a Pressure Vessel web application calculates the fall in gas pressure in a pressure vessel with time when the valve at the end of the vessel is opened. You can find the application on the web page <https://atkinsonscience.co.uk/WebApps/Aerospace/PressureVessel.aspx>. Also on this page you can download a theory guide which describes the theory and assumptions on which the application is based.

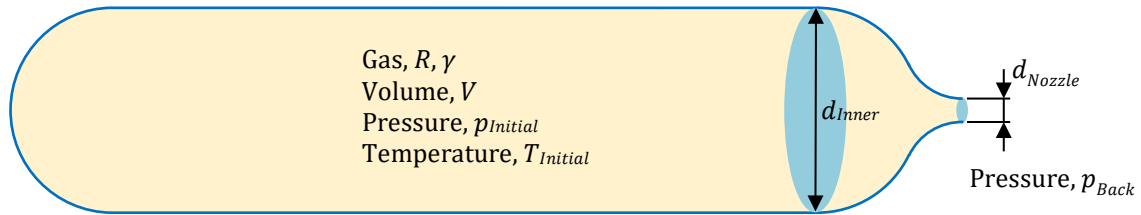
If the vessel is insulated or the discharge is very rapid then there will be very little heat flow through the vessel wall during the discharge and the temperature of the gas will fall (adiabatic discharge). If the vessel is uninsulated and the discharge is very slow then heat will flow through the vessel wall and the temperature of the gas will be maintained (isothermal discharge). Usually, the discharge will be somewhere between these two extremes, so the web application displays the curve of gas pressure against time for both cases.

In most cases the pressure in the vessel will be so high that the flow will choke after the valve is opened, then after the pressure has dropped sufficiently the flow will unchoke. The web application calculates the fall in pressure in the vessel through the period of choked flow and through the period of unchoked flow until the discharge is complete.

## 2 Pressure vessel

The pressure vessel is shown in Figure 1. The vessel has volume  $V$  [m<sup>3</sup>] and inner diameter  $d_{Inner}$  [m]. The end of the vessel tapers to a hole of diameter  $d_{Nozzle}$  [m] through which the gas discharges.

**Figure 1 Pressure vessel**



The user must supply the specific gas constant  $R$  [J kg<sup>-1</sup> K<sup>-1</sup>] and the ratio of specific heats  $\gamma$  [ ] of the gas. When the valve is opened the gas is at pressure  $p_{Initial}$  [bar] and temperature  $T_{Initial}$  [K]. Note that the pressure is the *absolute* pressure. The surrounding pressure into which the vessel discharges is called the *back pressure*,  $p_{Back}$  [bar]. Usually, the back pressure is the atmospheric pressure.

Table 1 gives values of  $R$  for  $\gamma$  some common gases. Values for other gases can be found on the web site <https://www.engineeringtoolbox.com/>.

**Table 1  $R$  and  $\gamma$  for some common gases**

Gas	$R$ [J kg <sup>-1</sup> K <sup>-1</sup> ]	$\gamma$
Acetylene	319.32	1.30
Air	287.05	1.40
Argon	208.13	1.66
N-butane	143.05	1.18
Iso-butane	143.05	1.19
Carbon dioxide	188.92	1.28
Carbon monoxide	296.84	1.40
Chlorine	117.26	1.33
Ethane	276.51	1.18
Ethylene	296.39	1.24
Helium	2077.1	1.66
N-Hexane	96.48	1.06
Hydrogen	4124.2	1.41
Methane	518.28	1.32
Nitrogen	296.80	1.40
Oxygen	259.84	1.40
Propane	188.56	1.13

### 3 User interface

The user interface of the web application is shown in Figure 2. The web application has been set up for a pressure vessel with a volume  $V$  of 0.05 m<sup>3</sup>, an inner diameter  $d_{Inner}$  of 0.22 m, and a nozzle diameter  $d_{Nozzle}$  of 0.005 m (5 mm). The gas is air (for which the specific gas constant  $R$  is 287.053 J kg<sup>-1</sup> K<sup>-1</sup> and the ratio of specific heats  $\gamma$  is 1.4). The initial gas pressure  $p_{Initial}$  is 10 bar and the initial gas temperature  $T_{Initial}$  is 298.15 K (25°C). The back pressure  $p_{Back}$  is 1 atm. (1.01325 bar).

When the user clicks the Calculate button, the application displays the time taken to complete the adiabatic discharge in one text box and the time taken to complete the isothermal discharge in another text box. The isothermal discharge always takes longer to complete than the adiabatic discharge. The application also creates a chart displaying a red curve, which is the gas pressure and against time for the adiabatic discharge, and a blue curve, which is the gas pressure and against time for the isothermal discharge. The chart also displays a purple horizontal line, which represents the pressure at which the nozzle unchokes (the *critical pressure*), and a black line, which represents the back pressure. If the initial gas pressure is below the critical pressure, then there is no purple line.

**Figure 2 User interface**

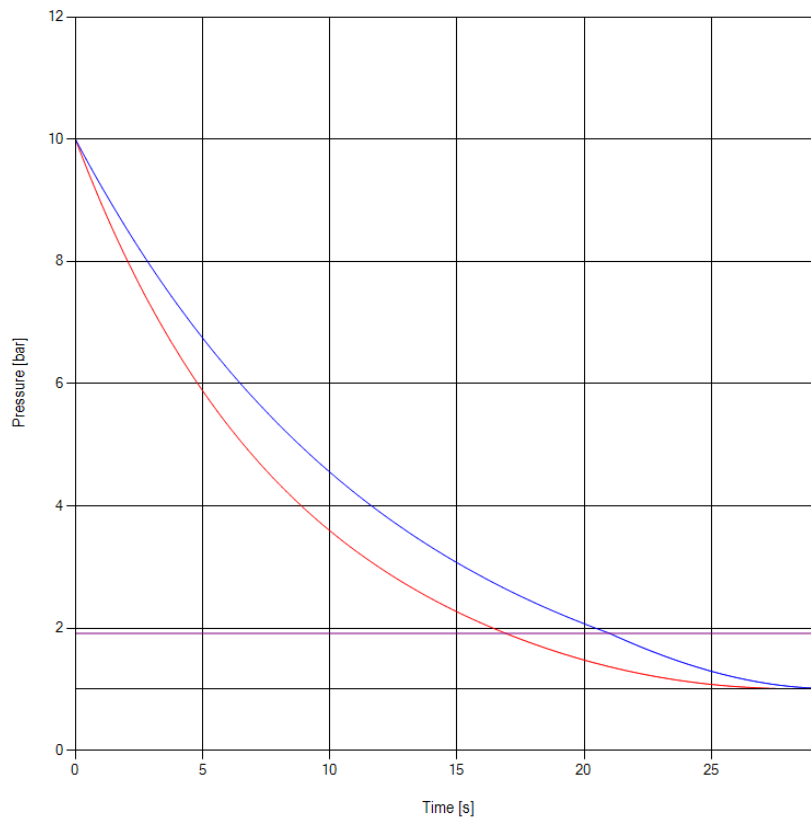
**Discharge of a Pressure Vessel**

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 Download the [Theory Guide](#) in PDF format

Vessel dimensions		Gas properties	
Volume	<input type="text" value="0.05"/> m <sup>3</sup>	Spec. gas constant	<input type="text" value="287.053"/> J kg <sup>-1</sup> K <sup>-1</sup>
Inner diameter	<input type="text" value="0.22"/> m	Ratio of spec. heats	<input type="text" value="1.4"/>
Nozzle diameter	<input type="text" value="0.005"/> m	Init. gas pressure	<input type="text" value="10.0"/> bar
		Init. gas temperature	<input type="text" value="298.15"/> K
		Back pressure	<input type="text" value="1.01325"/> bar

Adiabatic discharge		Isothermal discharge	
Discharge time	<input type="text" value="27.5934"/> s	Discharge time	<input type="text" value="29.3481"/> s

Legend			
Adiabatic discharge	Isothermal discharge	Unchoking	Back pressure





## 4 Ranges of the input variables

Table 2 lists the lower and upper limits of the input variables. We have assumed that the pressure vessel is either a cylinder with spherical end-caps or a sphere. If we increase the inner diameter  $d_{Inner}$  for a given volume  $V$ , then a cylindrical vessel will shrink in length and become a sphere when  $d_{Inner}$  reaches  $(6V/\pi)^{1/3}$ , making this the upper limit for  $d_{Inner}$ .

**Table 2 Lower and upper limits of input variables**

Variable	Lower limit	Upper limit
Volume $V$ [m <sup>3</sup> ]	$10^{-6}$ (1 cubic centimetre)	10
Inner diameter $d_{Inner}$ [m]	0.01 (1 centimetre)	$\left(\frac{6V}{\pi}\right)^{1/3}$
Nozzle diameter $d_{Nozzle}$ [m]	0.0001 (0.1 millimetre)	$d_{Inner}/2$
Specific gas constant $R$ [J kg <sup>-1</sup> K <sup>-1</sup> ]	50	5000
Ratio of specific heats $\gamma$ [ ]	1.02	1.7
Initial pressure $p_{Initial}$ [bar]	$1.2 \times p_{Back}$	$100 \times p_{Back}$
Initial temperature $T_{Initial}$ [K]	200	2500
Back pressure $p_{Back}$ [bar]	0.1	10

If the user enters the value of a variable that is outside the lower and upper limits of the variable then the web application will issue an error message and remind the user of the variable's lower and upper limits.