Research on Determining the Isentropic Exponent of Air Using the Clement and Desormes Method

The isentropic exponent, which is the ratio of specific heats at constant pressure and constant volume respectively has various applications in the industry. The objective of this lab was to determine the isentropic coefficient of air. This was achieved by taking measurements of pressure difference from the laboratory and using Clement and Desormes method to calculate isentropic coefficient. The next objective was to estimate the heat transfer coefficient that is responsible for the resultant heat transfer between the air and the vessel walls. Furthermore, a decision had to be made on which process is best between quick and slow release valve. The pressure difference was recorded every minute until stabilization was reached before and after a valve-release was performed, for both quick and slow release. The isentropic exponent was then calculated for each method and compared with the theoretical isentropic exponent of 1. 4 at 298K. The average isentropic exponents for slow and quick release were determined to be 1. 22 and 1. 21 with deviations from the theoretical value by 13. 76% and 12. 74% respectively. Microsoft Excel solver was used to determine heat transfer coefficient as 1. 55W/m2 K and 1. 59W/m2 K for quick and slow release respectively. The fast release process was established to be the best since it had a lower deviation of the isentropic exponent from the theoretical isentropic exponent. The Cp and Cv values of air were determined to be 46. 41J/mol K and 38. 10J/mol K respectively for quick release, the slow release Cv and Cp values were determined to be 40. 12J/mol K and 51. 36J/mol K.

Introduction

The isentropic exponent is the ratio of the isobaric heat capacity (Cp) and the isochoric heat capacity (Cv). According to relevant theory, for an ideal gas which is diatomic like air, the isentropic exponent is equal to 1, 4. The aim of the experiment is to use the experimental data obtained to determine the isentropic exponent of air using the Clement and Desormes method and compare that to the theoretical value, with the secondary aims being to determine Cp and Cv of air, the heat transfer coefficient due to the heat transfer that takes place between air and the walls of the vessel, and which, between the quick and slow release of the air in the vessel, is the most efficient.

Literature Review

Polytropic Index

A polytropic process, a process where work is done on or by the gas, defines the process that takes place during the compression and expansion of a gas, and it obeys the following law: Where n is the polytropic index. The value of n depends on the conditions of the process, (i. e. Isothermal, adiabatic, etc). This report looks at process conducted under isentropic conditions, defined as a reversible adiabatic process, so when the process is isentropic and the gas is ideal, gamma instead of the letter n is used. The new equation which is termed the Poisson's law is as follows. Where, gamma, is the isentropic exponent. The isentropic exponent is defined as the ratio of heat capacity at constant pressure and at constant volume, which gives the approximated value of 1, 4 for an ideal and diatomic gas like air.

Clement and Desormes Method

A successful application of this method requires a list of assumptions to be made. These assumptions included the following:

- Air behaves as an ideal gas
- The specific heats, Cp and Cv do not vary with temperature.
- The expansion of the gas is adiabatic after quick release
- The temperature in the lab remains constant for the duration of the experiment
- The heat transfer coefficient is constant throughout the surface area of the vessel.
- The determination of the isentropic exponent from Clement-Desormes method is described by two important steps which are described below:

Adiabatic Compression

The first step involves the adiabatic compression of a gas in a closed container. A pump is used to pressurize air contained in the vessel resulting in a change in a temperature and pressure increase above atmospheric. As soon as the pump is released, the system cools in an isochoric manner and after a certain time, the conditions within the vessel tend towards atmospheric. The heat transfer occurs from the air to the vessel walls as the walls temperature are assumed to be at ambient temperature.

Adiabatic Expansion

The pressure is reduced by quickly opening a release valve. The temperature of the gas drops down to ambient conditions. Isochoric heating occurs and the walls heat up the air, the heat transfer occurs from the walls to the air. This is achieved by performing a slow release (slow opening and closing of valve) once the vessel has stabilized from prior pressurization.

Poisson’s Law

At the equilibrium of both processes, the head are recorded and used to determine the isentropic exponent. Poisson’s law is then used in determining the experimental value of gamma for air.

Heat Transfer Coefficient

During isochoric heating and cooling of the gas, convective heat transfer occurs between the gas and walls of the gas.

Results and Discussion

Isentropic Exponent (Gamma)

For each method (quick- release and slow- release), 5 runs with different amounts of pumping was conducted to estimate the isentropic exponents based off the different manometer heights measured. The isentropic exponent ? for each consecutive run for both quick and slow release are represented and prove to be different from the theoretical isentropic exponent of 1. 4. By taking the manometer height difference readings for both expansion and compression, the average isentropic exponents for both cases are 1. 22 and 1. 21 respectively with an error of 12. 54% and 13. 76% relative to the isentropic exponent of 1. 4 obtained at 298K. This can be accounted for by human error given that the pressure change is very small within the time interval taken. Other factors that contributed to the varying value for the is isentropic coefficient could be that the air pumped in was a mixture of gases that have varying composition at different regions.

Heat Capacities at constant volume and pressure

From our thermodynamics book, we learnt that Cp and Cv are constants, the Cp and Cv values for air at are 1. 005 kJ/kg K and 0. 718 kJ/kg K respectively. The Cp and Cv values were calculated for each experimental run for both quick or slow releasing method. The respective average values for both methods show that the specific heats for slow release were bigger as compared to the quick release method. When a gas is heated at a constant volume, the heat energy supplied raises the temperature and thus the internal energy of the gas because the gas cannot expand any further beyond the containment of the constant volume it’s kept in. The heat capacity of liquid is a function of temperature, pressure has a slight effect on the Cv unless we working at high pressure. In our system the increase in pressure means increase in temperature, they have a direct proportional relationship thus increase in the Cv. The Cv values for slow release are greater than of fast release in most runs because there pressure was high and the temperature thereof. The above principle applies for our Cp which is a function of both pressure and temperature. The greater the pressure the higher the temperature in a system our value for Cp will be larger than a system that has lower pressure and temperature in comparison. This accounts for values of slow release being bigger than quick release.

Heat Transfer Coefficient

To establish if the process is indeed adiabatic, the expected heat transfer coefficient should be presumed to be 0 W/ m2K however it cannot be exact due to human error and inconsistencies in opening the inlet valve when the desired number of pumps have been conducted. The table below shows the relevant heat transfer coefficients calculated for the quick and slow release methods using Microsoft Excel solver to determine the theoretical height difference by assuming an arbitrary heat transfer coefficient value. For quick- release the Uo for steady state determination with increasing 60 second time intervals.

Conclusion

The expected isentropic exponent from the assumption that air behaves as an ideal gas was 1. 4 at 298K. However, average isentropic coefficients of 1. 22 and 1. 21 were determined using Clement and Desormes method for quick and slow release respectively. This indicated that air was not ideal. This was further used to establish that the slow release is the best process since it had an isentropic exponent closer to that of ideality. The Cp and Cv values of air were determined to be 29. 12 J/kmol K and 20. 8 J/kmol K respectively. Heat transfer coefficients were calculated and found to be 1. 55W/m2 K and 1. 59W/m2 K for quick and slow release respectively.