

PAPER • OPEN ACCESS

A New Experimental Device of Isentropic Process for Ideal Gas

To cite this article: Chao Ning *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **252** 042093

View the [article online](#) for updates and enhancements.

A New Experimental Device of Isentropic Process for Ideal Gas

Chao Ning^a, Jian Li^b, Chunan Ai and Suyuan Wei^c

Xi'an Research Inst. Of Hi-Tech, Xi'an 710025, China

^achao_ning@163.com, ^b1625492@qq.com, ^cwei_suyuan2002@163.com

Abstract. A isentropic experimental device was designed to verify the equation of isentropic process. The experimental data were analyzed to find out the causes of excessive data errors, and the improvement was made. The improved isentropic experimental device has stable performance, and the error is within a reasonable range. It can meet the experimental needs of thermal engineering courses in Colleges and universities.

1. Introduction

The isentropic process is an important content of the thermal engineering course in Colleges and universities, and it is also a learning difficulty. In order to promote students to understand and master the concept of isentropic process, some colleges and universities have designed some isentropic experimental devices to assist theoretical teaching, enhance students' intuitive and perceptual understanding, and deepen students' understanding of knowledge points [1, 2]. For the same purpose, the author designs a new type of isentropic experimental device, which has been tested and improved on this basis. The improved isentropic experimental device is easy to operate and can verify the equation of isentropic process more accurately without the need for students to have sophisticated operation skills. It has a wider applicability.

2. Principle

If there is no heat exchange between the system and environment, this process is called adiabatic process. When the adiabatic process is reversible, the process is an isentropic process [3]. Thus

$$ds = \frac{\delta q}{T} = 0 \quad (1)$$

For ideal gas, the relation of entropy change in isentropic process is as follows

$$ds = c_{v0} \frac{dp}{p} + c_{p0} \frac{dv}{v} = 0 \quad (2)$$

We can get

$$\frac{dp}{p} + \gamma \frac{dv}{v} = 0 \quad (3)$$



When the specific heat capacity is constant, the specific heat ratio γ is also constant. Therefore, the integral of the above formula can be expressed as

$$pv^\gamma = \text{const} \quad (4)$$

For ideal gases, the specific heat ratio is equal to the adiabatic index (isentropic index).

3. Initial experimental device and analysis of experimental results

The initial experimental device we designed is shown in Fig. 1. The device consists of piston cylinder, gas valve, pipeline, gas cylinder, pressure transmitter and digital display meter.

The specific experimental step is to fill the piston cylinder, pipeline and gas cylinder with air, change the piston motion state by controlling the rod, cause the change of air volume. Thus, the pressure value of the gas in the airtight space is changed, and the pressure information transmitted with the pressure transmitter is displayed by the digital display meter [4].

Record the initial volume V , initial pressure P and the corresponding volume and pressure P_i , V_i in the sealed space. Substitute them into the state equation of the constant entropy process of ideal gas and verify the equation of the constant entropy process. Record the initial volume V , initial pressure P in the airtight space. Then record the corresponding volume V_i and pressure P_i . Substitute them into the state equation of the isentropic process of ideal gas to verify the equation.

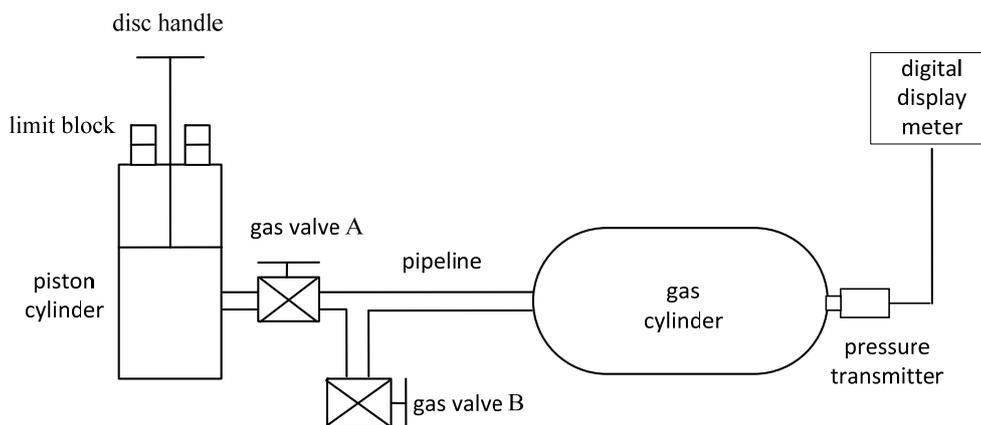


Figure 1. Initial experimental device of isentropic process

In order to realize the isentropic process, the experimental device needs to satisfy two conditions, one is adiabatic, and the other is reversible. The adiabatic process refers to the process that occurs without heat transfer between the system and the environment. In order to realize the adiabatic process, we can use the adiabatic material manufacturing system or the adiabatic material coating system. Compared with this expensive method, we can adopt a relatively simple measure, that is, to make the process go faster, so that the system can not have significant heat exchange with the environment. Such a process can be approximated as an adiabatic process. When we design the experimental device and the experimental process, we make the process of gas compression and expansion go faster and can be approximated as an adiabatic process [2].

The reversible process must be a quasi-static process without dissipation [3]. The piston in the experimental device has friction when expanding and compressing in the cylinder, but the friction loss is relatively small and can be ignored. The key is to realize the quasi-static process. According to [3], the thermodynamic system experiences a series of equilibrium states in the quasi-static process and deviates from the equilibrium state infinitely at each state change. This requires students to stretch or compress the piston of the cylinder as uniformly as possible to change the gas volume of the system.

Fig 2 and Fig 3 are P-V diagrams of gas compression and expansion with isentropic experimental device to verify the isentropic process equation. From the two diagrams, it can be seen that the variation trend of measured and theoretical values is the same whether in compression or expansion process. In the initial stage of the process, the relative error is small, but with the process going on, the error between the measured value and the theoretical value becomes larger and larger. At the end of the process, the relative error has exceeded 10%.

By analyzing the isentropic experimental device, the possible factors causing errors are heat dissipation loss, friction loss and non-quasi-static process loss, in which the errors caused by heat dissipation loss and friction loss are relatively small, while the errors caused by non-quasi-static process loss are relatively large. The quasi-static process is composed of a series of equilibrium states, which deviate infinitesimally from the equilibrium state and quickly reach the next equilibrium state when the state changes. For the isentropic experimental device, the realization of quasi-static process requires that the experimenter can strictly control the piston to move at a uniform speed in the process of compression or expansion. In the actual experiment process, it is very difficult to achieve this artificially. With the process going on, the experimenter must exert more and more force on the piston rod in order to ensure the piston movement, which can not guarantee uniform speed at all. So the experimental error increases with the progress of the process. Moreover, the experimental error varies from person to person. The students with good operation skills can make the piston motion relatively uniform, and the experimental error is less than that of the students with ordinary experimental skills.

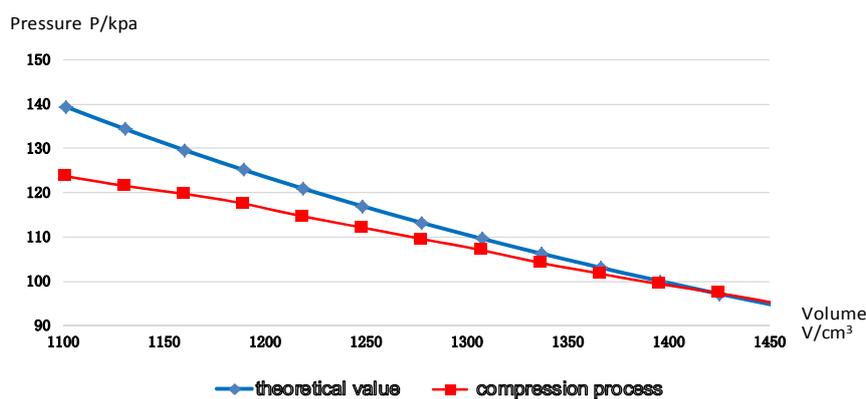


Figure 2. P-V chart of air isentropic compression process in initial experimental device

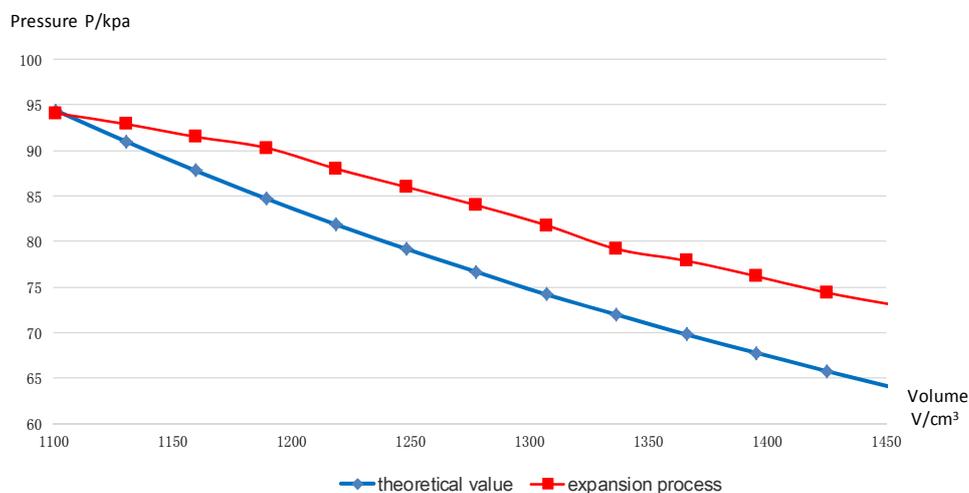


Figure 3. P-V chart of air isentropic expansion process in initial experimental device

4. Improvement of experimental device and analysis of experimental results

In view of the problems existing in the initial isentropic experimental device, we have improved the design. The redesigned experimental device is shown in Fig. 4. The device consists of industrial computer, stepping motor, screw slider, piston cylinder, gas cylinder, pressure transmitter, and control circuit and gas pipeline. The improved isentropic experimental device is driven by industrial computer through control circuit to rotate stepper motor. The piston is driven to move uniformly in the cylinder by the screw slider to complete the compression or expansion of the gas. The gas pressure of the system is collected by industrial computer through pressure transmitter in real time, and the gas volume change of the system can also be obtained in real time.

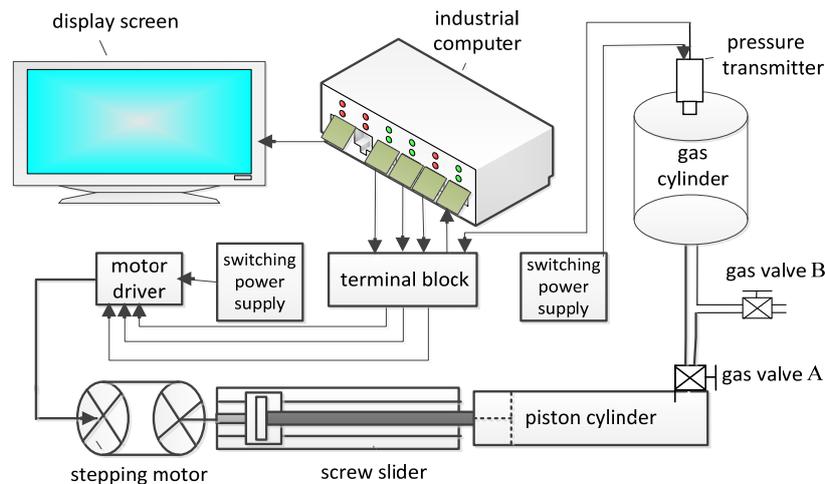


Figure 4. Improved experimental device of isentropic process

Fig .5 and Fig .6 are P-V diagrams of gas compression and expansion using improved isentropic experimental device to verify the isentropic process equation.

From the two figures, it can be seen that the measured values are very close to the theoretical values, and the maximum error is only 3.8% for the improved isentropic experimental device, whether in compression or expansion process. This shows that we have correctly analyzed the causes of the excessive error of the initial isentropic experimental device and taken appropriate measures to improve it. Different students do not need specific operating skills, but can successfully complete the experiment under the simple guidance of the teacher. The experimental data are reasonable and the dispersion is very small.

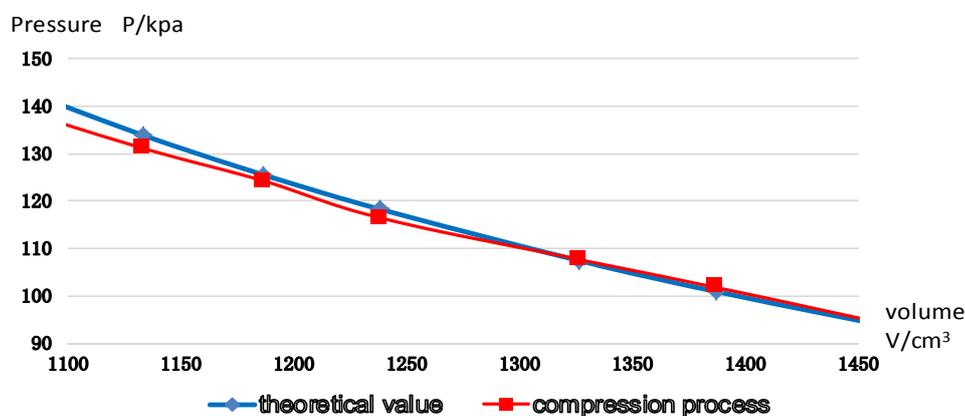


Figure 5. P-V chart of air isentropic compression process in improved experimental device

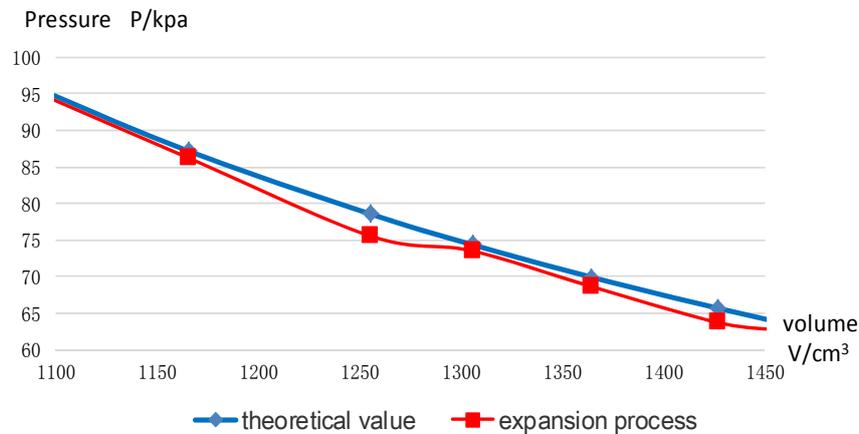


Figure 6. P-V chart of air isentropic expansion process in improved experimental device

5. Conclusion

The isentropic process is an ideal process. There are some irreversible factors in the actual process. It is inevitable that there are always errors between the experimental data of the actual process and the theoretical data of the isentropic process. The key is to analyze the role of these irreversible factors in the error, find out the main reasons and improve them. In this isentropic experimental device, the possible factors causing errors are heat dissipation loss, friction loss and non-quasi-static process loss. Among these losses, the errors caused by heat dissipation loss and friction loss are relatively small, while the errors caused by non-quasi-static process loss are relatively large. In this paper, stepping motor is used to drive the piston instead of manpower to drive the piston, so that the compression and expansion process is closer to quasi-static state, thus reducing the error from more than 10% to only 3.8%. Good experimental verification effect of isentropy is achieved.

References

- [1] Feng Gao. Experimental study of gas isothermal and adiabatic process measured by pressure sensors. *Experimental Technology and Management* [J]. 2010, 27 (5), pp.50-52.
- [2] Congying Sun . Simple experiment setup for the realization of quasi-static adiabatic process and calculation of related gas parameters [J]. *Physics Experimentation*, 2009, 29 (11), pp.27-28.
- [3] Ziqiang Hua. *Engineering Thermodynamics* [M]. The Fourth Edition. BeiJing: Higher Education Press (2009)
- [4] Jian Li. A experimental device of isentropic process for ideal gas. Number of utility model patent: ZL 2015 2 1042889.6