Innovation and Practice of Thermal Engineering Fundamentals in Engineering Education

Qin Zhang, Manlai Zhang*, Shanbiao Zhang
School of Mechanical Engineering, Yangtze University, Jingzhou, Hubei, China
**Corresponding Author*

Abstract: Thermal Engineering Fundamentals is an essential component of engineering disciplines, particularly for majors such as mechanical, energy, power, and environmental engineering. It encompasses fundamental theories such as thermodynamics and heat transfer, as well as practical skills related to the conversion and utilization of thermal energy. This paper aims to explore the innovation and practice in the teaching of the Thermal Engineering Fundamentals course. By introducing case-based teaching methods, using Stirling engine models as teaching aids, integrating experiments with simulations, and adopting project-based learning, the goal is to enhance students' engineering thinking abilities and their capacity to solve practical problems, laying a solid foundation for their future career development.

Keywords: Thermal Engineering Fundamentals; Engineering Education; Innovation; Practice

1. Introduction

With the rapid development of science and technology, thermal technology is increasingly widely applied in fields such as machinery, energy, power, and environment [1]. Consequently, the requirements for in-depth understanding of basic thermal theories and practical abilities are continuously increasing. Therefore, the teaching reform of the Thermal Engineering Fundamentals course is of particular importance.

2. Analysis of the Current Situation of the Thermal Engineering Fundamentals Course

At present, a common problem in the Thermal Engineering Fundamentals course is the disconnection between theory and practice [2]. Students' understanding of thermal engineering principles remains superficial, and they lack the ability to solve practical problems. In addition, the teaching methods are single, lacking in interaction and practical sessions, making it difficult to stimulate students' learning interests and innovative thinking.

3. Introduce the Case-Based Teaching Method

Take the teaching of the Rankine cycle in steam power plants as an example [3]. In the Thermal Engineering Fundamentals course, the Rankine cycle is an important teaching content. The Rankine cycle is a thermodynamic cycle widely used in steam power plants. It is named after the Scottish engineer William John Macquorn Rankine [4]. By playing a video of a power plant, point out the main components of the Rankine cycle and provide the engineering background. Combine the key contents in previous courses, such as the two-phase region of water vapor and the dryness fraction, analyze the working principle of the steam turbine, and pave the way for new teaching contents. Through PPT and blackboard writing derivations, explain in detail the working principles of key devices such as boilers, condensers, and water pumps, and introduce the principle of the Rankine cycle, which is the key content of the course.

Thoroughly analyze the constituent processes of the Rankine cycle to make students understand and remember, avoiding rote memorization. For example, the Rankine cycle consists of an isentropic compression process (Pump, in which the condensate is pressurized by the pump and sent to the boiler, during which the pressure of the water increases, but the temperature hardly changes), an isobaric heating process (Boiler, in which the high-pressure condensate is heated to a high-temperature and high-pressure steam state in the boiler, and this process is carried out at a constant pressure, so the temperature of the water-steam mixture remains unchanged until all the water is converted into steam), an isentropic expansion process (Turbine, in which the high-temperature and high-pressure steam is sent to the turbine to expand and do work, converting thermal energy into mechanical energy, during which the pressure and temperature of the steam decrease, but the entropy remains unchanged), and an isobaric condensation process (Condenser, in which the low-pressure steam coming out of the turbine enters the condenser, where it is cooled and partially condensed into water, and this process is carried out at a constant pressure, and the steam releases heat and the temperature decreases). After these four processes are completed, the water returns to its initial state and is ready to start a new cycle.

Combine actual engineering problems, link theory with practice, and explain the engineering applications of the Rankine cycle. In teaching, introduce the production process of a thermal power plant, guide students to simplify practical problems into problems studied in engineering thermodynamics courses, and analyze them using the theory of the Rankine cycle. For example, the Rankine cycle has great potential in improving energy utilization efficiency and reducing environmental impacts, and is currently widely used in domestic waste heat power generation fields, cement, metallurgy, steel and other industries, making important contributions to China's energy-saving and emission-reduction cause [5]. Another example is the combined application of the Rankine cycle and the Kalina power cycle, which realizes the complementary advantages at different flue-gas temperatures [6].

Introduce the latest research results of the Rankine cycle to make students understand cutting-edge technologies. For example, introduce the Rankine cycle process design method based on thermal matching, which depends on establishing the matching relationship between the temperature and heat map curves of the heat source and the working fluid. This method can optimize the performance between the heat source and the working fluid without presetting the cycle configuration. Another example is to introduce the supercritical steam Rankine cycle process of the supercritical reheat-regeneration process, which can not only heat the feed water, but also heat the reheat steam, thereby further improving the thermal efficiency of the Rankine cycle, and the thermal efficiency of the steam Rankine cycle can even exceed that of the S-CO2 cycle.

In the experimental teaching session, measure parameters such as the thermal efficiency, relative internal efficiency, and friction loss of the Rankine cycle device under different working conditions, compare and analyze the experimental results with the ideal Rankine cycle, and propose methods to improve the thermal efficiency of the actual Rankine cycle and measures to improve the laboratory Rankine cycle device. Incorporate self-experiment and innovative experiment into experimental teaching to stimulate students' learning enthusiasm and basic scientific research ability, and provide references for innovative experimental teaching.

4. Introduce the Model-Based Teaching Method

Take the teaching of the Stirling engine model as an example [7]. The Stirling cycle is also a thermodynamic cycle, which consists of two isothermal processes and two isochoric processes. It realizes the conversion of thermal energy into mechanical energy through regenerative heat transfer at constant volume and was first proposed by the British engineer Robert Stirling in 1816.

Use the Stirling engine model as a teaching aid to assist teaching in the teaching chapter of the Stirling cycle. Through on-site demonstration of the Stirling cycle experiment, observe the experimental phenomena, and analyze the thermodynamic processes of the gaseous working medium. During the teaching process, clarify the basic principles of the Stirling cycle and strengthen students' understanding of the Stirling cycle. At the same time, guide students to think about how to make the actual power cycle approach the highly efficient ideal Carnot cycle.

Use the Stirling cycle model to design experimental teaching, so that students can deeply understand the thermal engineering processes through hands-on operations and simulation experiments. Through the study of the Stirling cycle, students can understand the working principles of heat engines and how to convert thermal energy into mechanical energy. Through the research and analysis of the Stirling cycle, students can think about how to improve the existing heat engine designs, increase thermal efficiency, and reduce energy consumption. The teaching of the Stirling cycle model can cover multiple discipline areas, such as thermodynamics, fluid mechanics, and heat transfer. Through the interdisciplinary teaching method, students can establish connections between different disciplines and improve their comprehensive analysis and problem-solving abilities.

Guide students to optimize the Stirling cycle model. For example, improve the thermal efficiency of the Stirling cycle by improving the design of heat exchangers, reducing heat losses, and increasing the thermal conductivity of the working medium; reduce energy losses by optimizing the structural design of the Stirling engine, such as improving the sealing performance of pistons and cylinders, reducing friction losses, and optimizing the structure of heat exchangers;

Increasing the power density of the Stirling engine enables it to output more power under the same volume or mass; improve the dynamic response ability of the Stirling engine by optimizing the control system and improving the flow characteristics of the working medium; improve the reliability and durability of the Stirling engine by optimizing material selection, improving manufacturing processes, and strengthening maintenance; reduce the manufacturing and maintenance costs of the Stirling engine by optimizing the design, adopting more economical materials and manufacturing processes, and increasing production efficiency.

5. Combination of Experiment and Simulation

Use virtual simulation software and laboratory equipment to enhance students' hands-on ability and intuitive feeling, and improve their understanding of thermal engineering processes.

5.1 Simulation Experiment of Superheated Steam Temperature Cascade Control System

Simulate the superheated steam temperature cascade control system through simulation software to understand the system structure and performance characteristics [8]. In the simulation experiment, students can adjust the control parameters and observe the influence of the parameter changes of the controlled object under different loads on the control quality of the control system, thereby deepening their understanding of control theory.

5.2 Three-Dimensional Virtual Reality Simulation of Thermal Power Plants

Use the three-dimensional virtual reality simulation platform of thermal power plants [9], and students can carry out professional skill training in a virtual environment, such as the operation and management of the thermal power generation system. This simulation experiment helps students have an intuitive understanding and operation experience of the real engineering system without safety risks.

5.3 Virtual Simulation Software for Engineering Thermodynamics Fundamentals

Through the virtual simulation software for engineering thermodynamics fundamentals, students can carry out various thermodynamic experiments, such as gas thermodynamic processes, saturated steam characteristics, etc [10].

These software provide experimental equipment and operation experiences consistent with the actual laboratory, enabling students to conduct experimental operations and data analysis in a safe virtual environment. Through these teaching activities that combine experiments and simulations, students can not only obtain practical experience in theoretical learning, but also explore and verify thermal engineering principles in a safe virtual environment, and improve their ability to solve practical engineering problems.

6. Project-Based Learning

Project-based learning is a student-centered teaching method, which promotes students' active learning and in-depth understanding through simulated or actual engineering projects [11]. In the teaching of Thermal Engineering Fundamentals, project-based learning sets up small projects to encourage student teamwork, from theoretical design to practical production, which can help students combine theoretical knowledge with practical engineering applications and comprehensively improve their comprehensive abilities such as solving complex engineering problems.

Take the performance optimization project of a thermal power plant as an example [12]. The student team is responsible for the performance evaluation and optimization of a simulated or actual small-scale thermal power plant. Students need to apply basic thermal engineering knowledge such as thermodynamics, heat transfer, and fluid mechanics to analyze the energy conversion efficiency of the thermal power plant, identify bottlenecks in the system, and propose improvement measures.

The implementation steps are as follows: data collection, students collect the operating data of the thermal power plant, including steam temperature, pressure, flow rate, as well as fuel consumption and power output; system analysis, use simulation software to simulate each component of the thermal power plant, analyze energy loss and efficiency problems; scheme design, based on the analysis results, students design improvement schemes, which may include adjusting boiler combustion parameters, optimizing steam turbine blade design, or improving heat exchanger performance; scheme implementation and evaluation, implement the improvement scheme in the simulation environment, evaluate its impact on the performance of the thermal power plant, and conduct a cost-benefit analysis.

The success of the project depends not only on the accuracy of theoretical analysis and scheme design, but also on teamwork, project management, and the actual verification of the final improvement effect.

Through such project-based learning, students can apply basic thermal engineering knowledge in the actual engineering background, improve their engineering practical ability and innovative thinking. This teaching method helps students better understand the basic theories of thermal engineering and lays a solid foundation for future engineering practice.

7. Teaching Effects and Reflections

Through the implementation of the above innovative teaching methods, students have a more solid grasp of the basic theories of thermal engineering, and their ability to solve practical problems has been significantly enhanced. At the same time, students' learning interests and innovative abilities have also been improved. However, how to further optimize the course content to make it closer to engineering practice still needs continuous exploration.

8. Conclusion

The teaching reform of the Thermal Engineering Fundamentals course is crucial for enhancing students' engineering thinking abilities and their capacity to solve practical problems. Through the implementation of methods such as case-based teaching, model-based teaching, experimental and simulation integration, and project-based learning, students can deepen their theoretical understanding while solving practical problems. This approach not only increases students' interest and participation in learning but also helps cultivate their engineering practical abilities and innovative thinking, laying a solid foundation for their future career development.

Acknowledgements

The work was supported by the Hubei Province New Engineering Construction Project (XGK01050); 2025 Teaching Reform Research Project of Yangtze University（JY2025029).

References

[1] Zhang Q, Zhang M. Evaluation of "Foundation of Thermal Engineering" Based on Engineering Certification and OBE. Higher Education and Practice, 2024, 1 (5).
[2] Zhang Xuemin, Li Yinran, An Zhoujian, et al. Teaching Reform of Thermal Engineering Fundamentals Course under the Background of Engineering Education Professional Certification: Taking Lanzhou University of Technology as an Example . University Education, 2023, (04): 69 - 71.
[3] Xue Caihong, Nan Hui. Exploration on the Reform of Ideological and Political Teaching Mode in "Thermal Engineering Fundamentals" Course. Industrial & Science Tribune, 2023, 22(20): 168 - 170.
[4] Zhang Xuemin, Li Yinran, Wang Yingmei, et al. A Preliminary Study on the Teaching Reform of "Thermal Engineering Fundamentals" Course under the Background of Engineering Education Certification. Education Teaching Forum, 2021, (28): 72 - 75.
[5] Wang Yan, Zhou Xiangkui, Li Ying. Research on the Cross - penetration of Thermal Engineering Fundamentals Course Content and Its Teaching Reform Exploration. Henan Education (Higher Education), 2020, (12): 85 - 87.
[6] Wang Fang, Mi Tengge. Research and Practice on the Teaching Reform of "Thermal Engineering Fundamentals" Course for Mechanical Majors in the "Internet +" Era. Education Modernization, 2019, 6(02): 72 - 74. DOI:

10.16541/j.cnki.2095 - 8420.2019.02.022.
[7] Xi Xinming, Yan Xiaoli. Research on the Teaching Reform of Thermal Engineering Fundamentals Course Based on the Cultivation of Innovative Talents. Higher Agricultural Education, 2011, (09): 46 - 48. DOI: 10.13839/j.cnki.hae.2011.09.002.
[8] Wang Hongyan, Tang Chan. A Preliminary Study on the Module - based Teaching Reform of Thermal Engineering Fundamentals Courses. China Electric Power Education, 2011, (17): 75 - 76.
[9] Guo Yu, Ma Limin, Shang Linlin. Construction and Research of the Comprehensive Platform for Experimental Teaching of Thermal Engineering Fundamentals Course. Education Modernization, 2019, 6(82): 162 - 163. DOI: 10.16541/j.cnki.2095 - 8420.2019.82.072.
[10] Wang Youtang, Zheng Bin, Sun Peng, et al. Exploration of Hybrid Teaching Methods for Thermal Engineering Fundamentals Course with Fewer Class Hours // Science and Engineering Research Center. Proceedings of 2018 3rd International Conference on Education, Management and Systems Engineering (EMSE 2018). School of Transportation and Vehicle Engineering, Shandong University of Technology, 2018: 4.
[11] Hu Changxing, Li Wei, Gao Fuyan, et al. The Role and Significance of Thermal Engineering Fundamentals Virtual Experiments in Professional Experiments: Taking the Teaching Reform of Energy and Environmental Engineering Professional Experiments in Ningbo Institute of Technology, Zhejiang University as an Example. Education Teaching Forum, 2014, (14): 267 - 268.
[12] Xi Xinming, Sun Tao. Research on the Experimental Teaching Reform of Thermal Engineering Fundamentals Based on the Cultivation of Innovative Talents. Higher Agricultural Education, 2011, (07): 53 - 55.