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Curriculum Reform and Practice of Hydrogen Energy and Fuel Cells Based on Industry-Education Integration

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Abstract: Against the backdrop of continuous advancement of the "Dual Carbon" strategy, hydrogen energy has become an important direction for China's energy structure transformation. The rapid development of the hydrogen energy and fuel cell industry has raised higher requirements for compound talents with theoretical foundation, engineering practical ability and interdisciplinary literacy. At present, the course Hydrogen Energy and Fuel Cell still has contradictions between limited class hours and complicated knowledge systems, outdated textbook contents lagging behind industrial technology iteration, insufficient practical teaching resources and uneven regional distribution of industrial chains. Traditional cramming teaching can hardly meet the demands of cultivating application-oriented talents. Based on the concept of industry-education integration, this paper reconstructs three types of engineering project modules including low-carbon hydrogen production process design, fuel cell stack performance optimization and deduction of cutting-edge hydrogen energy technologies, and constructs a dual-line integrated teaching path of "online autonomous learning — offline collaborative discussion — project achievement presentation". Meanwhile, an outcome-oriented assessment system consisting of self-evaluation, team mutual evaluation as well as evaluation by teachers and enterprise experts is established. The reform aims to connect basic theories with industrial practice, and improve students' capabilities in engineering design, techno-economic analysis, teamwork and high-order critical thinking, so as to provide references for cultivating application-oriented talents in the hydrogen energy field.

Keywords: Hydrogen energy and fuel cell; Industry-education integration; Project-based teaching; Cultivation of application-oriented talents

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1. Introduction: The call of the times for new energy talent cultivation in universities under the dual carbon strategy

1.1. Transformation pressure of global and China's energy structure and establishment of strategic attributes of hydrogen energy

At present, global energy consumption is still dominated by fossil fuels such as coal, petroleum and natural gas. Restricted by resource endowments, fossil fuels have long accounted for a high proportion in China's primary energy production and consumption, leading to increasingly prominent problems including carbon emissions and environmental pollution as well as energy security [1]. With the proposal of carbon peaking and carbon neutrality goals, China's energy system is accelerating the transformation towards cleanliness, low carbon, and diversification.

Hydrogen energy features wide sources, high energy density, clean utilization and suitability for large-scale and long-cycle energy storage. It can be applied to fields such as renewable energy consumption, transportation, industrial decarbonization and distributed energy. The Medium and Long-Term Plan for the Development of Hydrogen Energy Industry (2022-2035) issued in 2022 further clarified the energy attributes and strategic positioning of hydrogen energy.

The hydrogen energy industrial chain covers hydrogen production, storage, transportation, refueling and terminal utilization, involving interdisciplinary knowledge including electrochemistry, materials, thermodynamics, chemical processes, control and economic evaluation. China's hydrogen energy industry is transforming from demonstration application to large-scale and high-quality development, yet it still faces various engineering difficulties. Green hydrogen preparation relies heavily on precious metal catalysts and suffers from insufficient adaptability to fluctuating power supplies and high system costs; the coupling of traditional hydrogen production and carbon capture may bring additional energy consumption and economic costs; fuel cells are restricted by manufacturing costs, service life, and stability under complex working conditions.

These problems bear obvious interdisciplinary and comprehensive engineering characteristics, which cannot be solved merely by theoretical knowledge of a single field. The hydrogen energy industry is in urgent need of compound talents who can understand basic principles, complete engineering design and possess capabilities of system analysis, technical evaluation and collaborative innovation.

1.2. Development trend and engineering application difficulties of the whole hydrogen energy industrial chain

Hydrogen Energy and Fuel Cell is an important course for majors including New Energy Materials and Devices, Energy Chemical Engineering and related disciplines. Its main contents cover fuel cell principles, hydrogen production, storage and transportation, key materials, system integration and technology development trends [2]. Linking basic material theories with downstream engineering applications, this course serves as an important carrier to cultivate students' cognition of new energy systems and engineering practical abilities.

Traditional teaching generally follows the sequence of textbook chapters and focuses on knowledge transmission, while seldom guiding students to analyze real engineering problems. Although students can memorize basic concepts and working principles, they often fail to comprehensively apply knowledge when confronted with tasks such as technical route comparison, system design, and engineering decision-making. Therefore, it is necessary to integrate industrial problems, engineering standards and technological frontiers into curriculum teaching. Through industry-education integration and project-based teaching, scattered theoretical knowledge can be transformed into engineering tasks with specific application scenarios, enabling students to master knowledge, form methodologies and enhance innovative capabilities in the process of problem analysis, scheme design and achievement evaluation [3].

2. Main problems faced by curriculum teaching

2.1. Structural contradiction between limited class hours and complicated knowledge system

The course covers contents including hydrogen production principles, fuel cell types, key materials, testing evaluation, system control and industrial application, featuring wide knowledge span, strong interdisciplinarity and fast updating speed, while actual teaching hours are relatively limited. If teachers pursue full coverage of knowledge points, classroom teaching tends to be one-way cramming; if each content is elaborated in detail, the teaching schedule cannot be completed. Students lack time for discussion, presentation and practice, and teachers can hardly grasp their knowledge mastery in a timely manner. Eventually, knowledge points are easily fragmented, and students can only recite concepts without forming a complete cognition of the industrial chain and systematic engineering thinking.

2.2. Teaching contents lag behind industrial technology iteration

Technologies such as fuel cell catalysts, membrane electrodes, electrolyzers and hydrogen storage materials are continuously updated, and relevant industrial standards, cost structures and application scenarios are also changing constantly. In contrast, some textbooks still focus on classic principles and mature technologies, with insufficient introduction to new technologies such as novel electrolytic water hydrogen production, renewable energy coupling, fuel cell durability and full life cycle evaluation.

Some teachers lack practical experience in enterprises, so classroom cases mostly stay at the level of principle explanation and technical overview, rarely involving practical issues such as equipment selection, process constraints, cost control and operation and maintenance. As a result, students have insufficient understanding of industrial demands, technical boundaries and engineering evaluation standards.

2.3. Insufficient practical resources and spatial mismatch of industrial chains

Hydrogen is flammable, explosive and has high storage and transportation requirements. Hydrogen production systems and fuel cell experimental equipment are expensive with strict maintenance and safety management standards, making it difficult for many universities to build experimental platforms covering the complete industrial chain. Courseware, animations and videos can assist students in understanding basic principles, yet they cannot fully replace engineering design, simulation analysis and experimental operation.

In addition, there are certain regional differences in the distribution of renewable hydrogen production projects and fuel cell terminal applications in China [4]. Restricted by equipment and regional conditions, students can hardly systematically contact the whole process of hydrogen production, storage, transportation and application, and classroom knowledge cannot be closely linked with specific engineering scenarios.

3. Reconstruction of engineering project modules based on industry-education integration

Targeting the above problems, the course takes typical tasks in the hydrogen energy industrial chain as the main line, and integrates scattered knowledge into three progressive engineering projects. Project 1 focuses on hydrogen production technical routes and economic & environmental evaluation; Project 2 centers on collaborative design of fuel cell materials and structures as well as performance; Project 3 targets discrimination and scientific deduction of cutting-edge hydrogen energy technologies, forming a competency training path from basic application to comprehensive innovation.

3.1. Project 1: Low-carbon hydrogen production process design and techno-economic evaluation

Set against the background of constructing a low-carbon hydrogen production system in a certain region, the project requires students to compare technical routes including alkaline electrolysis, proton exchange membrane electrolysis and solid oxide electrolysis, and analyze constraints such as catalysts, operating temperature, working pressure, dynamic response and equipment costs.

Teachers do not directly provide the so-called optimal route, but supply regional energy structure, load curves, hydrogen consumption scale and equipment parameters. Students shall complete data retrieval, index screening and scheme comparison. Based on technical analysis, each group further conducts full-life-cycle carbon emission and techno-economic evaluation, comparing coal-based hydrogen production, natural gas reforming hydrogen production, industrial by-product hydrogen and renewable energy electrolytic hydrogen production. Evaluation contents include raw material costs, energy consumption, equipment investment, operation and maintenance, as well as storage and transportation expenses. The emission reduction benefits and energy consumption costs after coupling traditional hydrogen production with carbon capture, utilization and storage technologies are also discussed [5].

Through this project, students can realize that no hydrogen production technical route is absolutely superior independent of resource conditions and application scenarios. Actual engineering decision-making requires careful consideration of technical maturity, economic costs, environmental benefits, and regional supply-demand conditions.

3.2. Project 2: Fuel cell stack design and stability optimization

Taking proton exchange membrane fuel cells and solid oxide fuel cells as main research objects, the project requires students to complete material selection and structural design targeting indicators including power, efficiency, service life and cost.

Each group establishes a parameter matrix composed of electrolyte, catalytic layers, gas diffusion layers, bipolar plates and connectors, and analyzes matching relations among ionic conductivity, catalytic activity, porosity, corrosion resistance, thermal expansion coefficient and mechanical strength. The teaching focus shifts from simple introduction of component functions to analysis of coupling contradictions among components.

For example, increasing the ionic conductivity of solid oxide electrolytes usually requires high operating temperature, yet high temperature will aggravate interfacial reactions and element diffusion as well as thermal stress; thinning electrolytes can reduce ohmic loss, while increasing manufacturing difficulty and risk of mechanical failure; raising catalyst loading can improve reaction kinetics but push up manufacturing costs.

Students need to analyze activation loss, ohmic loss and mass transfer loss combined with polarization curves and impedance spectra, and propose schemes for material selection and structural optimization. There is no single standard answer for project acceptance; schemes are evaluated by industrial indicators including power density, attenuation rate and cost. Through multi-objective trade-off analysis, students can realize that fuel cell stack design is not simply the improvement of single material performance, but the systematic optimization of materials, structures, manufacturing processes and operating conditions.

3.3. Project 3: Scientific deduction of cutting-edge hydrogen energy technologies

To cultivate students' critical thinking and frontier awareness, the course selects emerging technologies such as electrolyte-free single-component fuel cells as open-ended projects. Such fuel cells break the traditional three-layer structure of anode-electrolyte-cathode, and adopt composite functional layers made of materials with both ion and electron conduction properties. Students need to explain their potential working mechanisms from perspectives including electrochemical reaction, carrier transport and gas diffusion as well as interfacial electric fields.

Two core questions are raised in the project: First, the porous single-layer structure lacks dense electrolyte separators, so will hydrogen and oxygen permeate each other and bring safety risks? Second, when both electronic and ionic phases exist simultaneously, how can internal electronic short circuits be avoided?

Teachers mainly evaluate the integrity of students' argumentation and evidence chains, without requiring them to accept established conclusions. Students shall analyze both potential advantages of new technologies in structural simplification and cost control, as well as uncertainties in mechanism interpretation, long-term stability and large-scale manufacturing, so as to form scientific thinking of "raising questions — establishing hypotheses — searching evidence — verifying conclusions".

4. Project-based teaching implementation of online preview & offline discussion

4.1. Online resources support pre-class learning before teaching

Adopting flipped classroom mode, the course produces short videos, micro-lessons and reading materials covering basic fuel cell principles, hydrogen production reaction kinetics, key materials and evaluation methods, and releases them via online platforms in advance [6].

Before launching each project, teachers synchronously release engineering scenarios, project task sheets, data materials and question lists, requiring students to finish preview tests and preliminary data retrieval. Online learning mainly covers basic concepts and common knowledge. Teachers sort out high-frequency questions based on platform feedback and deliver targeted explanations in class. This teaching mode alleviates the contradiction between limited class hours and complicated knowledge content, leaving more classroom time for problem analysis, scheme discussion, and achievement improvement.

4.2. Offline collaborative discussion and phased guidance

Offline teaching is divided into project groups of 3 to 5 students. Teachers spend about one third of class hours sorting out core logic, explaining typical cases and solving common problems. Students finish data analysis, scheme comparison, model construction and achievement presentation in the remaining time [7]. Teachers shift from knowledge lecturers to project organizers and process supervisors, providing methodological support at key links.

Each project is divided into stages of demand analysis, data research, scheme design, mid-term report and achievement polishing. Group members divide tasks according to requirements, and rotating presentations, random questioning and personal reflection records are adopted to ensure substantial participation of every student.

For physical hydrogen production and fuel cell experiments that are difficult to carry out, the course introduces process simulation, electrochemical simulation, and virtual experiments. Students can analyze changes in system efficiency, polarization loss and thermal management by adjusting temperature, pressure, flow and material parameters, which makes up for the shortage of experimental equipment to a certain extent [8].

6. Conclusion and prospect

Facing the demands of the Dual Carbon strategy and hydrogen energy industrial development, the course Hydrogen Energy and Fuel Cell needs to shift from knowledge indoctrination to competency cultivation. Targeting problems including insufficient class hours, outdated contents and scarce practical resources, this paper constructs three engineering project modules of low-carbon hydrogen production, fuel cell stack optimization and deduction of cutting-edge hydrogen technologies based on industry-education integration, and forms a teaching mode integrating online preview, offline discussion, digital simulation and multi-subject evaluation. The reform embeds scattered theoretical knowledge into real engineering problems, helps improve students' capabilities in system analysis, scheme design, techno-economic evaluation, teamwork and critical thinking, and promotes the connection between university basic research and industrial application.

In the future, the course can further introduce cutting-edge industrial issues such as distributed renewable hydrogen production, non-precious metal catalysts and storage-transport network optimization as well as adaptive control of electrolyzers. Efforts shall be made to strengthen the construction of school-enterprise shared experimental platforms and case resource libraries. Meanwhile, continuous collection of students' learning outcomes, feedback from enterprise experts, and graduates' job comments shall be carried out to perfect the curriculum goal achievement evaluation system and provide replicable and promotable teaching experience for cultivating high-quality application-oriented talents in the hydrogen energy field.

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