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# Integrated Application of MVR Evaporation and Distillation Technology in Uranium Purification and Conversion Process and Analysis of Its Energy-Saving Effect

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**Abstract:** This paper studies the integrated application of Mechanical Vapor Recompression (MVR) evaporation and distillation technology in uranium purification and conversion processes, as well as its energy-saving performance. As a key link in the nuclear fuel cycle, uranium purification and conversion have a vital impact on the economic efficiency and sustainability of the nuclear industry in terms of energy consumption and resource utilization rate. The combination of MVR evaporation and distillation technology realizes efficient cyclic utilization of energy and full recovery of waste heat. This paper elaborates on the process flow, equipment configuration, and energy-saving effect of the integrated system. Comparative analysis with traditional processes verifies that the integrated system boasts prominent advantages in energy consumption reduction, thermal efficiency improvement, and resource utilization enhancement. In addition, the application prospect and potential economic value of the integrated technology in uranium purification and conversion are discussed. This research provides new technical approaches and solutions for energy conservation, consumption reduction, and resource recycling in uranium purification and conversion processes.

**Keywords:** MVR evaporation; Distillation technology; Uranium purification and conversion; Energy-saving effect; Resource recycling

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## 1. Preface

Uranium purification and conversion are essential parts of the nuclear fuel cycle, during which a large number of by-products and wastes are generated. Based on an analysis of the existing technologies for uranium purification and conversion facilities in China, this paper explores feasible ways to recycle and reuse wastes so as to achieve low consumption and low emission. Given the increasingly severe energy and environmental challenges, energy conservation, consumption reduction, and resource recycling have become important research priorities for uranium purification and conversion. As high-efficiency and energy-saving separation technologies, MVR evaporation and distillation have been widely applied in chemical, pharmaceutical, food, and other industries [1]. The integrated application of these two technologies in uranium purification and conversion is expected to realize efficient energy recycling and full utilization of waste heat, thereby cutting energy consumption and improving resource utilization efficiency.

## 2. Principle and characteristics of MVR evaporation technology

MVR evaporation is a highly efficient and energy-saving evaporation technology [2]. It mechanically compresses the secondary steam generated by the evaporator to raise its pressure, temperature, and heat grade, and then recirculates the treated steam to the evaporator as a heat source. The core advantage of MVR evaporation lies in the cyclic reuse of steam and full utilization of waste heat, which greatly reduces energy consumption [3].

A typical MVR evaporation system consists of an evaporator, a compressor, a preheater, and a condenser. Uranyl nitrate solution is preheated in the preheater and then fed into the evaporator for heating and evaporation to produce secondary steam. After being compressed by the compressor, the secondary steam with elevated temperature and pressure re-enters the evaporator to serve as the heat source. The concentrated solution after evaporation is delivered to subsequent processes. The secondary steam is condensed into water in the condenser, and part of the condensate can be used as the heat source for the preheater to realize multi-stage heat utilization [4–6]. MVR evaporation technology delivers remarkable energy-saving performance.

## 3. Principle and characteristics of distillation technology

Distillation is an efficient separation technology that separates and purifies components of a mixture by virtue of their differences in volatility [7–8]. As a mainstream method for material separation and purification, it is widely used in chemical, pharmaceutical, food, and other sectors [9]. A distillation system is mainly composed of a reboiler, column trays, a condenser, and other components. The mixture to be separated is heated in the reboiler to generate steam. Mass and heat transfer take place between the rising steam and reflux liquid on the column trays to achieve component separation [10]. The purified components are condensed into liquid at the column top, and part of the condensate flows back into the column as reflux to sustain the separation process.

## 4. Integrated application of MVR evaporation and distillation technology

In the extraction stage of uranium purification and conversion, uranyl nitrate is transferred from the aqueous phase to the organic solvent, while non-extractable impurities and trace uranium remain in the nitric acid raffinate. Traditional treatment adopts direct alkali neutralization for the raffinate, which consumes massive lye and fails to recover nitric acid and uranium resources. Distillation technology can recover nitric acid and water from the raffinate and reduce the volume of uranium-bearing solution, creating favorable conditions for subsequent uranium recovery [11–12].

In the distillation unit, the uranium-containing nitric acid solution is heated to produce steam. Mass and heat transfer occur between the steam and reflux liquid on the packing to separate uranium from other components. High-purity water and nitric acid are extracted respectively from the column top and side line and returned to the production system for reuse, while uranium-bearing waste liquid is discharged from the column bottom for further uranium recovery. To fully utilize the heat generated during distillation and reduce energy consumption, MVR technology is adopted to compress the overhead steam of the distillation column to upgrade its heat grade, and the treated steam is reused for heating the nitric acid distillation process.

To produce qualified uranium trioxide ($UO_3$) particles via thermal denitration, the uranyl nitrate solution after extraction and purification needs to be concentrated to increase uranium content. MVR technology is applied in this process to cut evaporation energy consumption. In the MVR evaporation unit, preheated uranyl nitrate solution enters the evaporator and is heated to produce secondary steam. The secondary steam is compressed to increase its temperature and pressure, and then re-enters the evaporator as a heat source to realize steam recycling. This unit efficiently concentrates the uranyl nitrate solution. The secondary steam generated during concentration is washed and purified to recover uranium-bearing nitric acid solution. After partial nitric acid is further recovered via the distillation unit, the purified secondary steam is sent back to the system, lowering the nitric acid content in the steam.

The coupling and integration of MVR evaporation and distillation technology not only saves energy, but also realizes the recovery and reuse of nitric acid and water as well as volume reduction of uranium-bearing solution, making the entire process greener, more energy-efficient and more productive.

## 5. Process flow and equipment configuration of the integrated system

The integrated system mainly comprises two core units: the MVR evaporation unit and the distillation unit.

### 5.1. MVR evaporation unit

Main equipment: evaporator, compressor, preheater, and condenser.

Process flow: The uranyl nitrate solution is preheated and fed into the evaporator for evaporation to generate secondary steam. The secondary steam is compressed to raise its temperature and pressure, and then circulated back to the evaporator as a heat source. The uranium-bearing nitric acid solution recovered from washing and purification of secondary steam is delivered to the distillation unit together with extraction raffinate. A liquid level controller and a density controller are equipped to regulate the liquid level inside the evaporator and the density of concentrated solution.

### 5.2. Distillation unit

Main equipment: reboiler, column trays, condenser and related accessories.

Process flow: The uranium-containing nitric acid solution is heated in the reboiler to generate steam. Mass and heat transfer proceed between steam and reflux liquid on the packing for component separation. The purified overhead product is condensed into liquid, and part of the condensate flows back into the column as reflux. The residual liquid at the column bottom is transferred to follow-up processes. A temperature controller and a pressure controller are installed to stabilize the overhead temperature and bottom pressure of the column.

In addition, the integrated system is equipped with an automatic control system to realize automatic equipment operation and real-time monitoring of operating parameters. This configuration improves the efficiency and operational stability of uranium purification and conversion, reduces energy consumption, and achieves efficient energy utilization.

## 6. Analysis of energy-saving effect

Firstly, MVR evaporation technology compresses secondary steam to improve its temperature and heat grade and realize steam recycling. Different from traditional evaporation processes, it requires no external steam supply and achieves self-sufficient steam supply, thus cutting energy consumption substantially.

Secondly, distillation separates and purifies components by utilizing volatility differences. By adjusting parameters such as reflux ratio and maintaining stable operation, efficient component separation can be realized, which improves product quality and resource utilization rate.

Thirdly, the integrated system achieves multi-stage energy utilization and efficient cyclic use of energy. The overhead steam of the distillation column is recompressed by MVR equipment and used as the heat source for the distillation column bottom, greatly reducing heating energy consumption. Meanwhile, condensate from the MVR evaporation unit is used as the heat source of the preheater for material feeding, realizing cascaded heat utilization.

Compared with traditional processes, the integrated system shows distinct advantages in energy consumption reduction, thermal efficiency improvement, and resource utilization enhancement. The specific energy-saving performance is subject to system configuration, operating parameters, and raw material properties [13].

## 7. Application prospect and economic value

First of all, the integrated system realizes efficient energy recycling and full utilization of waste heat, and significantly reduces energy and resource consumption, which complies with the requirements of sustainable development. Against the backdrop of growing global energy and environmental concerns, energy conservation and resource recycling have become key development directions for the nuclear industry. Therefore, this integrated technology enjoys broad market prospects and great application potential.

Secondly, the integrated system improves product quality and resource utilization rate, and lowers production costs and environmental pollution [14]. Optimized process flow and equipment configuration ensure efficient, stable, and reliable operation of uranium purification and conversion, while reducing pollutant discharge and complying with environmental regulations [15].

Furthermore, the technology delivers remarkable economic and social benefits. It cuts production costs and environmental pollution treatment expenses by reducing energy and resource consumption. Meanwhile, improved product quality and resource utilization rate enhance corporate economic benefits and market competitiveness.

## 8. Conclusion

This paper studies the integrated application of MVR evaporation and distillation technology in uranium purification and conversion as well as its energy-saving effect. The results prove that the integrated system has prominent advantages in reducing energy consumption and improving thermal efficiency and resource utilization. Through process and equipment optimization, efficient energy circulation and full waste heat utilization are realized, which effectively cuts energy and resource consumption, lowers production costs, and mitigates environmental pollution.

With broad application prospects and considerable potential economic value, the integrated technology provides new technical ideas and solutions for energy conservation, consumption reduction, and resource recycling in uranium purification and conversion. With continuous technological progress and large-scale promotion, it will play an increasingly important role in the nuclear industry and make greater contributions to the sustainable development of nuclear energy.

## Disclosure statement

The authors declare no conflict of interest.

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