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The Separation Nozzle Process for Uranium Isotope Enrichment

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Introduction

In the separation nozzle process /1/ /2/ for the enrichment of U-235 isotope separation is achieved by the same basic mechanism as in the centrifuge method. However, the mechanical problems of highly stressed rotating machines are avoided, as the centrifugal forces are generated by the deflection of a high speed jet of uranium hexafluorid and a light auxiliary gas (Fig. 1). The light gas (H_2) which is present in a large molar excess, increases the flow velocity of the UF_6 and, hence, adds to the centrifugal force determining the separation.

The process has been developed at the Karlsruhe Nuclear Research Center. Since 1970, the German company, STEAG, has been involved in the technological development and commercial implementation /3/. In 1975, the Brazilian company, NUCLEBRAS, and

the German company, INTERATOM, joined the effort. The primary objective of the common activity is the construction of a separation nozzle demonstration plant with an annual capacity of about 200 t SWU.

The paper covers the most important steps in the technological development and the future prospects of the separation nozzle process.

Separation Elements

The optimum operating pressure of the nozzle systems is inversely proportional to their characteristic dimensions. As a high operating pressure is favorable for economical operation, the characteristic dimensions are chosen to be as small as possible.

One method of producing separation nozzle elements by mechanical means /1/ has been developed by the German company of Messerschmitt-Bölkow-Blohm, Munich. Another method based on the stacking of photo-etched metal foils, introduced by the German company of Siemens, will be described in more detail:

Fig. 2a shows a metal foil along the edges of which a large number of separation nozzles are etched together with ducts for the feed gas and for the heavy fraction. Stacking such foils produces separation nozzle assemblies ("chips") with considerable packing densities (Fig. 2b). As shown in Fig. 2c, they are installed in tubes to one half of which feed gas is supplied while the other half is used to remove the heavy fraction. The light fraction escapes to the outside of the tubes.

A largely automated production line for manufacturing photo-etched separation elements has been installed by Siemens. At present its capacity is about 2500 m of slit length per annum.

Separation Stages

Tests of large batches of mass produced separation nozzle elements and of the equipment needed for commercial implementation of the process are performed in two prototype separation

stages at Karlsruhe. Their main components are a separation element tank, a radial compressor and a gas cooler. Fig. 3 shows the separation elements being located into the so-called small stage. As can be seen, the separation elements are arranged as a compact unit for easy installation.

A typical test operation of the small stage is shown in Fig 4. Obviously the separation capacity, which amounts to nearly 300 SWU/a, is constant whithin the limits of error.

Cascade Design and Operation

In the demonstration plant a total of about 500 separation stages will be connected in series in order to produce enriched uranium containing 3% U-235 and to strip to some 0,3% the U-235 content in the waste. Fig. 5 shows a schematic representation of such a plant. The use of two types of stages with a 1:3 ratio of flows makes the performance approach that of a corresponding ideal cascade with an efficiency of approximately 90%.

A separation nozzle cascade produces a netupward transport of the light auxiliary gas, which is on the order of the stage throughput. To prevent enrichment of light gas in the cascade, the upward transport has to be extracted from the top and fed back to the bottom of a section, as illustrated in Fig. 5. For this purpose the light fractions of the top stages are processed in the so-called UF_6-recycle facilities shown in the figure. There the UF_6-content of the upward flow is stripped off with high efficiency and fed back to the feed flows of the top stages.

The flowsheet of such a facility comprises a special separation nozzle stage backed by a low temperature freeze-out heat exchanger system /3/. Experiments performed with UF_6/H_2 mixtures under process conditions have demonstrated that a UF_6-content of the light gas well below 1 ppm is easily achieved. Accordingly, only negligible losses of separative work are associated with the recirculation of the light gas from the tops to the bottoms of the cascade sections.

In the separation nozzle method, a high degree of stability is reached for the pressure distribution along the cascade, be-

cause local differences in the nozzle inlet pressure give rise to major local changes of the relatively pronounced upward transport mentioned in the previous section of the light additional gas in the sense of a stabilization. However, inherent stability of the UF_6 concentration along the cascade can be achieved only by proper choice of the characteristics and operating points of the plant components.

A ten stage pilot plant equipped with Roots compressors was built to work on these problems and served for experimental studies both of the steady state and the dynamic control behavior of separation nozzle cascades /4/. The UF_6 distribution was found to assume an inherently stable state under all operating conditions studied in the plant (Fig. 6 A). Without any active control measures the full anticipated multiplication of the elementary effect of uranium isotope separation was found (Fig. 6 B).

The situation is somewhat more complex with the centrifugal compressors used in commercial separation stages. However, if the operating point has been chosen properly and use is made of the gas dynamic properties of the backpressure valve of the heavy fraction, it is possible, to achieve inherent stability of the UF_6 distribution also with the compressors used in commercial application /3/.

Aspects of Basic Research

Besides the development work on process technology, extensive studies on the physics of the separation nozzle method have been performed at Karlsruhe. As an example Fig. 7 shows a separation nozzle system in which the streamline curvature is produced by two opposed jets. Separation experiments with UF_6/H_2 mixtures indicate that, under special conditions, the so-called opposing jet scheme may be economically attractive for the separation of uranium isotopes /6/. However, the first commercial implementation of the separation nozzle process is based on a system including a curved fixed wall.

Economics

To obtain reliable cost data on the separation nozzle process, a number of industries were commissioned to develop design and fabrication methods for the most important plant components under the requirements of mass production. Cost evaluations corresponding to the present development status result in specific investment costs which qualify the process as an economically attractive technique.

At the present state of development, the specific power consumption of the separation nozzle process corresponds approximately to that of the existing U.S. gaseous diffusion plants /7/. However, there is no doubt that a further significant reduction of that figure is to be expected.

Therefore the separation nozzle method can be recognized as an enrichment process which combines a reliable and comparatively simple technology with a high potential for further improvement.

References

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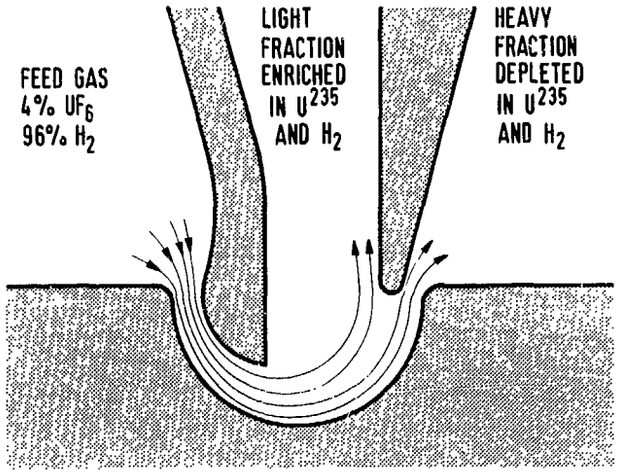

Fig. 1: Cross section of the separation nozzle system used in the commercial implementation of the process.

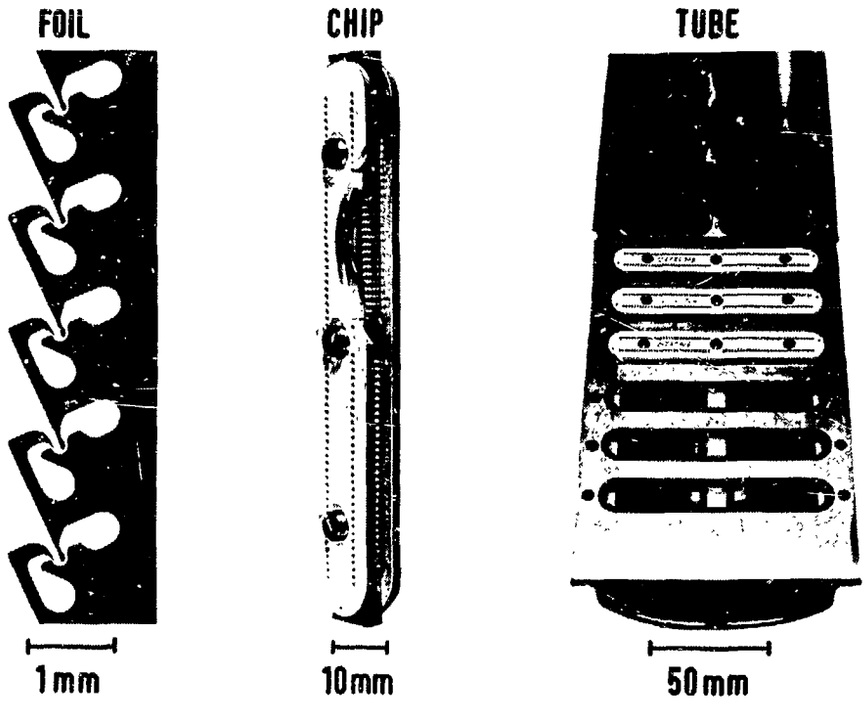

Fig. 2: The assembly of a commercial separation element manufactured by means of photo-etching (Siemens company, Munich).

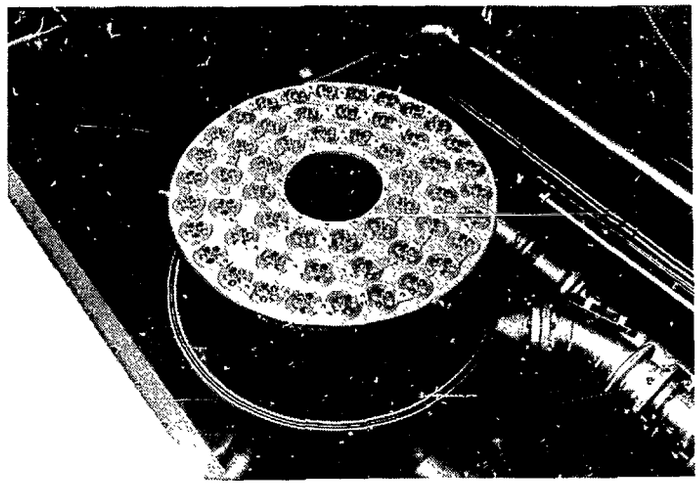

Fig. 3: Loading of the separation elements into the small separation stage. The separation elements are arranged as a compact unit to allow easy installation.

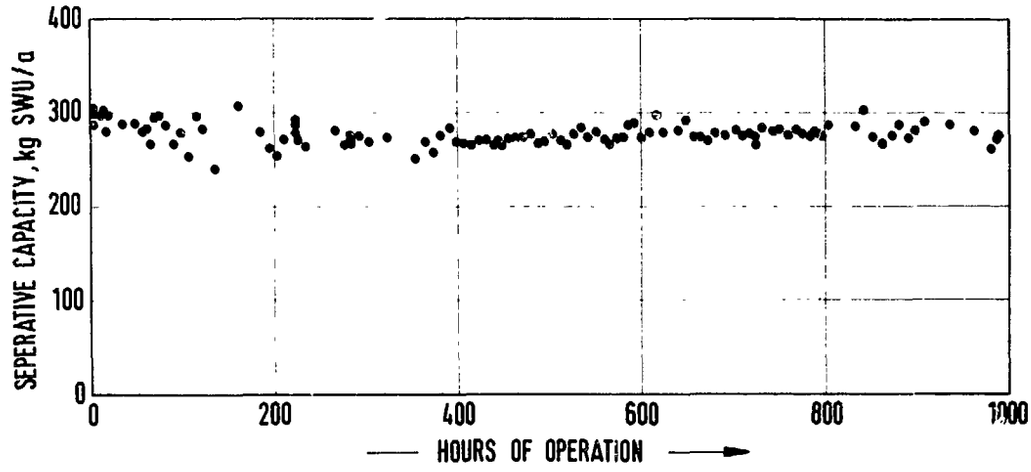

Fig. 4: Separation capacity vs time of the small separation stage.

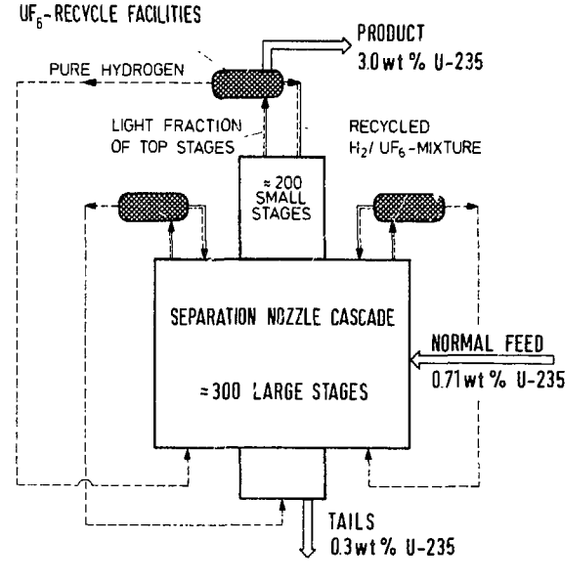

Fig. 5: Schematic representation of a separation nozzle cascade with UF_6 recycle facilities.

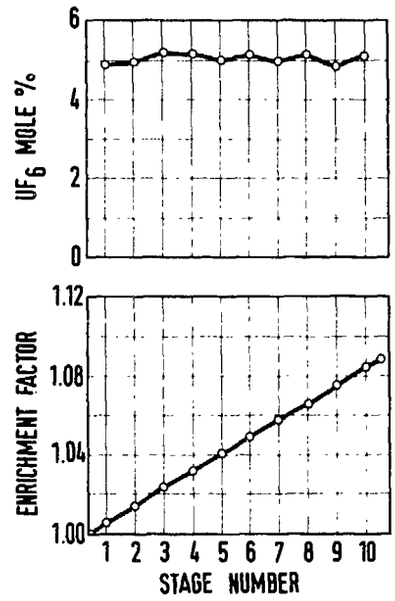

Fig. 6: Upper diagram: UF_6 mole fraction of the stages of the pilot plant, showing nearly uniform UF_6 content along the cascade.
Lower diagram: Experimental enrichment factor of Uranium 235 relative to the heavy fraction of stage 1.

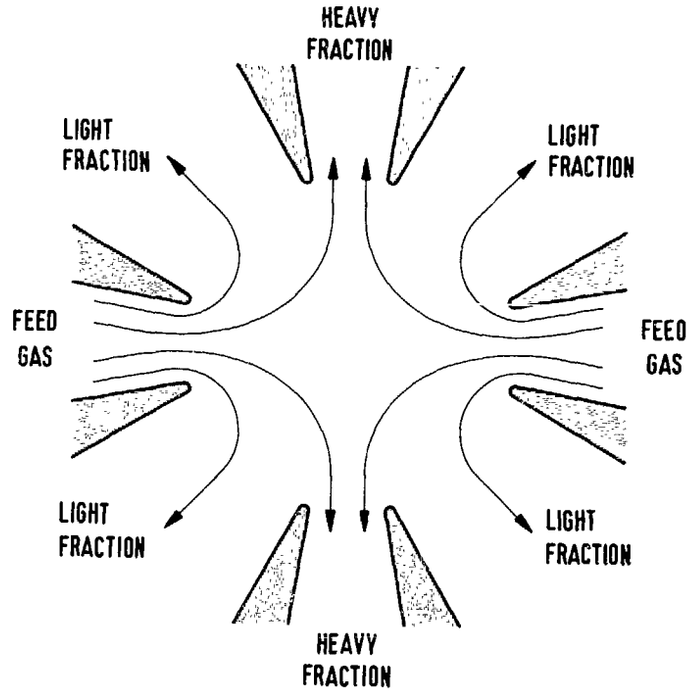

Fig. 7: Cross section of a separation nozzle system with opposed gas jets. /5/.