THE PRESENT LEVEL OF THE TECHNOLOGY
OF URANIUM ORE PROCESSING

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The raw material basis of the uranium industry is presently formed by poor, often complex ores, which are processed on a very large scale. The net cost of uranium production based on this material has been reduced by employing processes which are more effective and economic and by extensive automation. The article gives a review of the present level and development trends of uranium ore processing (mechanical concentration, preparation, leaching, separation processes, sorption, extraction) and the conditions for the use of these processes for ores of different composition. The basic industrial systems of processing the principal types of ores are described. A detailed analysis is given of the basic technical-economic indices of uranium ore processing factories.

Introduction

In recent years there has been a systematic reduction in the uranium content of mined ores, which, together with a constant increase in the production of uranium, requires a marked increase in the amount of ores for processing. In consequence, the uranium industry has now become one of the largest branches of the mining-and-metallurgical industry, and in relation to the amount of mined and processed ores is on a level with the principal older branches of the industry (copper or polymetallic mining for instance) and is far more advanced technically than the latter.

Moreover, each year sees an increase in the processing of difficult (high-carbonate, argillaceous, etc.) and complex ores (gold-uranium, uranium-vanadium, uranium-molybdenum, uranium-containing phosphorites, coal, shales, etc.).

All these factors have required a fundamental improvement in the uranium ore processing industry so as to increase the technical and economic efficiency of the various processes: increase in uranium extraction, improvement of the quality of concentrates, reduction of the consumption of reagents and electricity, increase in the output per man-shift, simplification of technological systems, etc. Radical changes in technology are associated with the introduction of sorption and, more recently, extraction processes in the uranium industry [1-3]. At the same time, other sections of the uranium ore processing industry have been considerably improved: mechanical concentration, preparation, leaching, separation processes, etc.

Mechanical Concentration

As a result of the use of low-grade uranium and complex ores, mechanical concentration processes are used on an increasingly wider scale.

The most promising development in this field is radiometric concentration, by means of which both the waste rock (from 10 to 50%) and the rich concentrates (uranium content up to 1% or more) are separated. Radiometric concentration of nonuniform (contrast) ores is already carried out in mines, where the ores are sorted directly into wagons or skips, or in automatic machines at radiometric control stations (RCS). The ore is then concentrated in radiometric sorting machines (batch or lump). The new Bou Noir ore-processing plant in the Forez Department (France), in which about 18% of the tailings and about 3.3% of the concentrate (uranium concentrate 1.2-1.5%) are separated from vein-type ore by means of skip RCS and belt sorters with scintillation counters, may serve as an effective example of radiometric concentration. The intermediate product is subjected to further concentration by suspension, flotation and chemical treatment.
Gravity methods of cleaning are also used in uranium ore processing (principally for vein-type ores). For example, concentration in heavy media is employed successfully at an experimental shale processing plant in Sweden, at the Radium Hill factory (Australia) and at other plants. Concentration in jigs, on vibrating tables and in spiral separators is employed at a number of factories in the U.S.A., Canada, and Congo and other countries. Thus, at the Farge Canyon factory (U.S.A.) a uranium-copper concentrate is separated by jigging in spiral separators and on tables; at the White Canyon factory (U.S.A.) about 80% of the waste is separated by combined cleaning (in spiral separators and by flotation) of low-grade ore [5].

In the majority of cases, flotation is used for extracting associated minerals or harmful impurities, for example for the extraction of sulfides of iron, copper and other metals from uranium ores (before and after leaching of the uranium). At the Beaverlodge factory (Canada) the sulfides are separated from the ore before soda leaching, because they increase the consumption of soda, contaminate the solutions and cause corrosion of the equipment. At the Bou Noir factory, flotation is used for secondary extraction of uranium from the low-grade product of radiometric concentration. Flotation is employed in a number of South African factories for preliminary cleaning of very low-grade raw material (waste products with a uranium content of 0.01-0.02%, from gold extraction plants) with extraction and concentration of about 90% of the pyrite and 50% of the uranium [6].

The new froth flotation process proposed by Sabba, in which aliphatic acids or their salts, forming insoluble soaps with uranium, are added to the uranium-containing solution or the dilute pulp after leaching, is of interest. These insoluble soaps are subsequently extracted by ordinary froth flotation [7].

For Canadian brannerite ores, investigations have been carried out on "frothless flotation," which consists in crushing the ore together with kerosene, xanthogenate being added. The pulp is then diluted with water and allowed to stand, brannerite being concentrated in the kerosene layer [8].

The method of selective crushing and classification, with separation of the waste sand, is used for cleaning low-grade (uranium content less than 0.1%) sandstones in the U.S.A. (in some cases they are subjected to additional washing with weak acid) [6]. Electromagnetic separation is sometimes employed for the separation of aggregates of uranium minerals and magnetite when cleaning uranium ores.

Preliminary Operations

For crushing sandstones, clays and other soft uranium ores, mainly hammer crushers, which can operate at a moisture content of not more than 10-15% in the ore, are employed. The use of a new type of hammer crusher with movable crushing plates, which has been employed with success at the Mabel factory (U.S.A.) for ore with a clay content of about 20% and a high moisture content, is therefore of great interest [8].

The "ball-less" grinding process, which has recently been successfully employed in certain Canadian and South African factories, is used for breaking up uranium ores. During this process the ore is ground by means of large lumps of ore. Ball-less grinding is more economical (the consumption of steel is markedly reduced) and gives better results during subsequent leaching of the uranium (smaller consumption of acid and particularly of oxidizing agent, greater extraction of uranium). Ball-less fine grinding after crushing and coarse grinding (to < 3 - 4 mm) by ordinary methods has been the most widely employed system of this type as yet. The ore is ground in ordinary mills, lumps of ore (with a particle size of < 76 + 40 mm) being added instead of balls. With this process the capacity of the mills is approximately 100% less than when steel balls are used, and the volume of the mill drum must be correspondingly increased.

Combined crushing and ball-less grinding in the same apparatus — a "percussive-air" or "cascade" mill — with a short drum of large diameter (from 3.6 to 8 m) gives a still greater effect. This simplifies considerably the whole crushing and grinding sections [9, 10].

Leaching of Uranium

Leaching is an important operation in the hydrometallurgical processing of uranium ores, determining the technological and economic indices of the process as a whole. The acid leaching method, which is the most economical method and gives a higher degree of uranium extraction, is presently widely employed. Soda leaching is used only for ores with a high carbonate content, because it usually gives a somewhat lesser extraction of uranium. However, as a result of the improvement of this method (use of autoclaves, catalysts, etc.) it has now begun to be employed for ores with lesser carbonate content. Thus, for example at the Moab factory (U.S.A.), where only acid