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(54) LASER ASSISTED JET NOZZLE ISOTOPE SEPARATION

(71) We, JERSEY NUCLEAR-AVCO ISOTOPES, INC., a Corporation of the State of Delaware, United States of America of 777 106th Avenue Northeast, C-00777 Bellevue, Washington 98009, United States of America do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed to be particularly described in and by the following statement:

The present invention relates to separation of fluent particles and in particular to laser enhancement of isotope separation based upon acceleration induced isotopic concentration and density gradients.

A gas in a force field such as gravity will, in equilibrium, have a density varying with distance away from the origin of the force. Scale height is a parameter which describes this density distribution. It identifies the distance from the origin in which the density exponentiates.

The scale height and density distribution also vary with the mass of the gas molecules. Thus in a mixture of gases, each of different mass, there will be a different scale height and density distribution for each component or gas type in the mixture. Since the scale heights and density distributions vary, the relative concentrations of the various gases also vary with distance, resulting in some separation of the gases in the mixture over large distances.

While the distances required for useful separation in a gravitional field are impractically large, these distances can be reduced by increasing the operative force through the use of centrifugal effects. Such systems are in use not only for separating chemically distinct molecules but also for separating isotopes such as occur in uranium (or sulphur) hexafluoride molecules.

An example of this type of prior art system is the jet nozzle, representative examples of which are shown in United States Patents 3,362,131, 3,668,080, 3,708,964, 3,853,529 and 3,877,892. In such a nozzle separation scheme a mixture of a molecular uranium compound, such as the uranium hexafluoride molecules in a carrier gas, like helium or hydrogen, is accelerated around a curved elongate channel into a plenum. A knife edge in the plenum separates the regions of different isotopic concentration established by the centrifugal force from acceleration around the curved channel.

The difference between the scale heights for the isotopic molecules to be separated is a parameter indicating the theoretical efficiency of the separation process. Since the scale heights for the different uranium isotopes will differ only in the ratio of the masses of the two isotopic molecules, 352:349 in the hexafluoride molecule, the scale height differences will be very slight, implying only a slight separation from such a nozzle. Repeated applications of the separation process of such a nozzle in further stages of similar nozzles will ultimately reach an isotope enrichment factor of utility.

While the difference in scale height attributable to mass differences may be only slight, it has been discovered that other factors which enter into the scale height may be employed to effect a greater difference in the scale height for the isotopic molecules thus improving the efficiency in their separation.

Brief summary of the invention

In accordance with a preferred teaching of the present invention, a system for isotope separation is described in which separation, dependent upon scale height differences, is augmented by changing a factor affecting scale height selectively, by isotope type. Specifically, a nozzle configuration is employed having an accelerating channel with an optically straight dimension transverse to the flow which is illuminated with tuned laser radiation to induce vibrational excitation of one isotope type in the mixture applied through the channel. The vibrational excitation, in the presence of a substantial proportion of carrier gas, is converted to a thermal excitation of the one isotope type. The selective thermal excitation of this one isotope type can be used to greatly augment the difference in scale height between the molecules of the two isotope types employed in the nozzle separation system. The result is a substantial increase in the efficiency of the separation system, requiring fewer stages of separation by improving the separation factor in each nozzle stage.

Since the nozzle shape is readily configured to extend a long, straight distance transverse to the gas flow, the application of a laser beam along a substantial length of material to be separated is efficiently achieved. In addition, the nozzle operates to permit some cooling of the isotope mixture as it expands after acceleration around the curved channel. This improves the selectivity with which vibrational excitation can be converted to thermal excitation of the one isotope type.

According to the invention there is provided a process for separating fluent particles having different masses comprising the steps of: driving a fluent mixture of such particles around a curved passage toward a septum oriented to divide the mixture thereby accelerating such particles to impart a centrifugal force thereto; inducing type selective heating of a selected particle type in said mixture prior to termination of such acceleration; receiving the fraction of the mixture flowing past in an outer surface of said septum in a first output conduit; and receiving the fraction of the mixture flowing past an inner surface of said septum in a second output conduit.

According to another aspect of the invention there is provided a system for separating fluent particles having different masses comprising: a curved passage; a septum beyond said curved passage; means for driving such fluent mixture of particles around said curved passage toward said septum thereby accelerating such particles to impart a centrifugal force thereto, the septum being oriented to divide the mixture flowing from the passage; means for inducing mass selective heating of a selected particle type in said mixture prior to termination of such acceleration; a first output conduit for receiving the fraction of the mixture flowing past an outer surface of said septum; and a second output conduit for receiving the fraction of the mixture flowing past an inner surface of said septum.

According to a still further aspect of the invention there is provided an apparatus for separating isotopes comprising: a curved conduit terminating in a plenum bounded by an extension of the radially outer wall of said conduit; means for driving a fluent mixture of particles of plural isotope types through said conduit into said plenum to induce a different density distribution for each isotope type in the mixture of plural isotopes in said plenum, the isotopes of greater mass tending toward the radially outer portion of said plenum; means for inducing isotopically selective heating of an isotope of the mixture of plural isotope types prior to their arrival at said plenum thereby to increase the difference in density distribution in said plenum; and a septum oriented to divide the mixture of plural isotope types flowing through said plenum into fractions of relatively heavier and lighter isotope components.

Description of the drawing

These and other features of the present invention are more fully set forth below in the exemplary and not limiting description of the invention and accompanying drawing of which:

Figure 1 is a sectional view of a nozzle with which the present invention is operative; and

Figure 2 is a system diagram of the present invention using a nozzle of the type illustrated in Figure 1.

Description of the invention

The present invention contemplates a method and apparatus for enhancing scale height difference in a system for isotope separation in which a fluent mixture of plural isotopes is accelerated around a curved channel to provide a high centrifugal force on the mixture. The invention, as described below, is preferably useful with the class of separation systems using a jet nozzle.

A representative nozzle, presented for purposes of illustration, is shown in Figure 1. It is to be noted that different nozzle designs exist as is indicated in the above-referenced United States patents and many of these may be utilized in the present invention. The nozzle shown in Figure 1 includes an inlet conduit 12 supplied with a gaseous mixture which, in the case of uranium enrichment, may typically be a 5% mole fraction of uranium hexafluoride (UF_6) and 95% mole fraction of hydrogen or helium. A pressure of one hundred to a few hundred mm of mercury is typical of the input feed pressure. The conduit 12 communicates with a curved channel 14 which may be seen from Figure 1 to be elongated in a direction 16 which is substantially transverse to the flow of the gas mixture through the curved channel 14. The gas mixture is pumped through the curved channel 14 and accelerated.

The curved channel 14 has an inner boundary wall 18 formed by a member 20 and outer boundary wall 22 formed by a member 24. Wall 22 typically has a radius of curvature of 0.1 mm and the separation of the walls 18 and 22 is typically 50-150 mean free paths. The radius of curvature for the boundary wall 18 is seen to be less than the radius of curvature for the boundary wall 22. The boundary wall 18 of the member 20 terminates abruptly at a point 26 by a vertically or substantially radially extending face 28 of the member 20 exposing a plenum 30 bounded radially outwardly by the surface 22. Each component of the expanded gaseous mixture within the plenum 30 may be characterized by a parameter termed "scale height" which is a distance in which the density of the gas exponentiates. Mathematically the scale height of each component is represented by the expression:

$$\text{Scale Height} = r \times kT/mv^2$$

where r is the radius of the curved flow, T is temperature, m is the particle mass, v is particle velocity and k is a constant. The scale height parameter is useful in quantifying the density distribution of the various components in the accelerated mixture, and in turn the degree of separation that may be achieved in the centrifugal force field. Accordingly, in a flow containing a mixture of isotopes, such as the $U\text{-}235F_6$ and $U\text{-}238F_6$ isotopes of the uranium hexafluoride molecule, the greater the scale height difference between the molcules, the greater will be their separation in the force field and the higher the concentration of the heavy fraction of the mixture along the outer wall 22, and the higher the concentration of the light fraction in regions radially inward of the wall 22.

A septum 32 having a knife edge 34 also extending traversely of the flow in the direction 16 is provided in the plenum 30 to divide the flow or separate different regions of the flow into output conduits 36 and 38. The output conduit 38 will contain a significantly higher concentration of heavier isotope particles, the $U\text{-}238F_6$ particles, and the conduit 36 which will contain a relatively lighter fraction with a higher concentration of the $U\text{-}235F_6$ particles than would occur in the input conduit 12.

An inspection of the equation presented above for scale height indicates that in the system described, the difference in scale height will essentially be attributable to a difference in the masses of the particles of the uranium hexafluoride molecules accelerated into the plenum 30. This difference, three mass units out of 352, can be seen to be very slight and accordingly, the degree to which separation occurs along the density gradient and eventually within the separate output conduits 36 and 38 will also be slight. Effective isotope separation thereby requires the cascading of a good many stages of individual nozzle separators of the type described above.

The present invention achieves an improvement in the separation of each individual nozzle of the type illustrated in Figure 1 by increasing the scale height parameter for a selected isotope, typically the $U\text{-}235F_6$ molecule, in order to increase the difference between the scale heights for the two isotopic particles and thereby improve the degree of their separation along the lines of force established within the plenum 30. This is achieved by providing an increase in the temperature for the $U\text{-}235F_6$ particle which, as can be seen from the above equation, will augment the scale height difference resulting solely from mass differences. The temperature increase is achieved by selectively exciting the $U\text{-}235F_6$ particles in the flow by laser-induced vibration of those particles. The vibration is then converted to a translation, or temperature rise in these particles when they collide with the molecules of the carrier gas.

Within this methodology for enhanced isotope separation, several characteristics of the nozzle separation scheme are developed to advantage. First of all, the nozzle may be configured to have an optically straight path in the inlet conduit 12 directly above the channel 14 in the direction 16 transverse to the flow of gas. A region 40 of laser illumination extends a substantial distance, typically a plurality of meters in the direction 16 to illuminate a long column of particles such as particles 42 of $U\text{-}235F_6$ and particles 44 of $U\text{-}238F_6$.

The centrifugal acceleration of the flow through channel 14 will induce a different density distribution for each particle type along a radial dimension with the lighter particles 42 more concentrated inward and the heavier particles 44 more concentrated outward. The augmented temperature selectively applied to the particles 42 will greatly reinforce this effect by changing the scale height and density distribution for these particles. A theoretical improvement in separation factor by two or more is possible.

The laser beam applied to the region 40 to produce vibrational excitation will typically be from an infrared laser operating at the 16 micron absorption line for UF_6 (or 10.6 microns for SF_6).

In Figure 2, the system of the present invention for enrichment by laser enhancement of the nozzle separation function is more fully illustraed. As shown there, a laser 50 applies a beam 52 to a nozzle 54 having the components illustrated above in Figure 1. The beam may be applied through windows as necessary and extend the substantial length of open inlet conduit 12 which may be, for example, two meters. The beam 52 exiting from the nozzle 54 may typically still have sufficient energy density to be useful for further enhancement of the scale height and may accordingly be redirectd through one or more additional nozzles 54, for example arranged in configurations illustrated in the above-referenced United States patents.

The above-described preferred embodiment of the present invention is presented for purposes of illustration only, the full scope of the invention to be defined in the following claims.

WHAT WE CLAIM IS:

1. A process for separating fluent particles having different masses comprising the steps of:

driving a fluent mixture of such particles around a curved passage toward a septum oriented to divide the mixture thereby accelerating such particles to impart a centrifugal force thereto;

inducing type selective heating of a selected particle type in said mixture prior to termination of such acceleration;

receiving the fraction of the mixture flowing past an outer surface of said septum in a first output conduit; and

receiving the fraction of the mixture flowing past an inner surface of said septum in a second output conduit.

2. The. process of Claim 1 wherein:

said mixture is a mixture of plural isotope types; and said selected particle type is a selected isotope type.

3. The process of Claim 2 wherein:

the passage in which said mixture of plural isotopes is accelerated extends in an optically straight path in a direction substantially transverse to the direction of flow of the accelerated mixture of plural isotope types; and

said step of inducing type selective heating includes the step of applying electromagnetic radiant energy in a direction parallel to said optically straight path transverse to the directional flow of the accelerated mixture of plural isotopes.

4. The process of Claim 3 wherein said step of applying electromagnetic radiant energy includes the step of applying infrared laser radiation.

5. The process of Claim 2 wherein said mixture of plural isotope types includes a mixture of uranium isotopes.

6. The process of Claim 5 wherein said step of inducing type selective heating includes the step of applying laser radiation tuned to produce isotopically selective excitation of the U-235 isotope in said mixture of plural isotope types.

7. The process of Claim 6 wherein said uranium isotopes occur in the uranium hexafluoride molecular form.

8. The process of Claim 7 wherein said laser radiation is tuned for selective vibrational excitation of the $U\text{-}235F_6$ molecule.

9. The process of Claim 2 wherein said mixture of plural isotope types includes a mixture of sulphur hexalfuoride isotopes.

10. The process of Claim 2 wherein the step of inducing type selective heating includes heating the isotopes in said mixture of said plural isotope types to increase the separation factor by at least a factor of two.

11. The process of Claim 1 wherein said fluent mixture of plural particle types includes molecules having components of a first isotope-type in combination with a carrier gas of lighter mass.

12. The process of Claim 11 wherein the carrier gas comprises approximately 95 mole percent of said fluent mixture of plural particle types.

13. The process of Claim 1 wherein said fluent mixture of plural particle types is cooled by expansion in being accelerated through said curved passage.

14. The process of Claim 1 wherein the type selective heating step includes the step of producing type selective vibrational excitation with resulting conversion of the vibrational energy to type selective translational energy.

15. A system for separating fluent particles having different masses comprising:

a curved passage;

a septum beyond said curved passage;

means for driving such fluent mixture of particles around said curved passage toward said septum thereby accelerating such particles to impart a centrifugal force thereto, the septum being oriented to divide the mixture flowing from the passage;

means for inducing mass selective heating of a selected particle type in said mixture prior to termination of such acceleration;

a first output conduit for receiving the fraction of the mixture flowing past an outer surface of said septum; and

a second output conduit for receiving the fraction of the mixture flowing past an inner surface of said septum.

16. The system of Claim 15 wherein;

said mixture is a mixture of plural isotope types; and said means for inducing mass selective heating comprises means for selectively heating a selected isotope type.

17. The system of Claim 16 wherein:

the passage in which said mixture of plural isotopes is accelerated extends in an optically straight path in a direction substantially transverse to the direction of flow of the accelerated mixture of plural isotope types; and

said means for inducing type selective heating includes means for applying electromagnetic radiant energy in a direction parallel to said optically straight path and transverse to the directional flow of the accelerated mixture of plural isotopes.

18. The system of Claim 17 wherein said means for applying electromagnetic radiant energy includes a source of infrared laser radiation.

19. The system of Claim 16 wherein said mixture of plural isotope types includes a mixture of uranium isotopes and said means for inducing mass-selective heating comprises means for selectively heating a selected uranium isotope type.

20. The system of Claim 19 wherein said radiation is tuned to produce isotopically selective excitation of the U-235 isotope in said mixture of plural isotope types.

21. The system of Claim 20 wherein said uranium isotopes occur in the uranium hexafluoride molecular form and said radiation is tuned to produce isotopically selective excitation of the uranium hexafluoride.

22. The system of Claim 21 wherein said laser radiation is tuned for selective vibrational excitation of the $U\text{-}235F_6$ molecule.

23. The system of Claim 16 wherein said mixture of plural isotope types includes a mixture of sulfur hexafluoride isotopes, and said radiation is tuned to produce isotopically selective excitation of the sulphur hexafluoride molecule.

24. The system of Claim 6 wherein the means for inducing type selective heating includes means for heating the isotopes in said mixture of said plural isotope types to increase the separation factor by at least a factor of two.

25. The system of Claim 15 further comprising means for supplying fluent mixture of plural particle types including molecules having components of a first isotope-type in combination with a carrier gas of lighter mass.

26. The system of Claim 25 wherein said means for supplying fluent mixture comprises means for supplying a fluent mixture comprising approximately 95 mole percent of carrier gas.

27. The system of Claim 15 including means for cooling said fluent mixture of plural particle types by expansion whilst being accelerated through said curved passage.

28. The system of Claim 15 wherein the type selective heating means includes means for producing type selective vibrational excitation with resulting conversion of the vibrational energy to type selective translational energy.

29. Apparatus for separating isotopes comprising:

a curved conduit terminating in a plenum bounded by an extension of the radially outer wall of said conduit;

means for driving a fluent mixture of particles of plural isotope types through said conduit into said plenum to induce a different density distribution for each isotope type in the mixture of plural isotopes in said plenum the isotopes of greater mass tending toward the radially outer portion of said plenum;

means for inducing isotopically selective heating of an isotope of the mixture of plural isotope types prior to their arrival at said plenum thereby to increase the difference in density distribution in said plenum; and

a septum oriented to divide the mixture of plural isotope types flowing through said plenum into fractions of relatively heavier and lighter isotope components.

30. The apparatus of Claim 29 wherein said means for inducing isotopically selective heating includes means for applying electromagnetic radiant energy to said mixture of particles of plural isotope types.

31. The apparatus of Claim 30 wherein said means for applying electromagnetic radiation includes an infrared laser.

32. The apparatus of Claim 31 wherein:

said curved conduit extends an optically straight distance in a direction transverse to the flow of accelerated fluent mixture of isotopes; and

said laser applies a beam of electromagnetic radiation to the mixture in a direction parallel to the optically straight distance.

33. Apparatus for separating isotopes substantially as hereinbefore described with reference to the accompanying drawings.

34. A process for enhancing effective isotope separation substantially as hereinbefore described with reference to the accompanying drawings.

CLEVELAND AND JOHNSON,
Chancery House,
Chancery Lane,
London WC2.
Chartered Patent Agents,
Agents for the Applicants.

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1583166 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*

FIG. 1

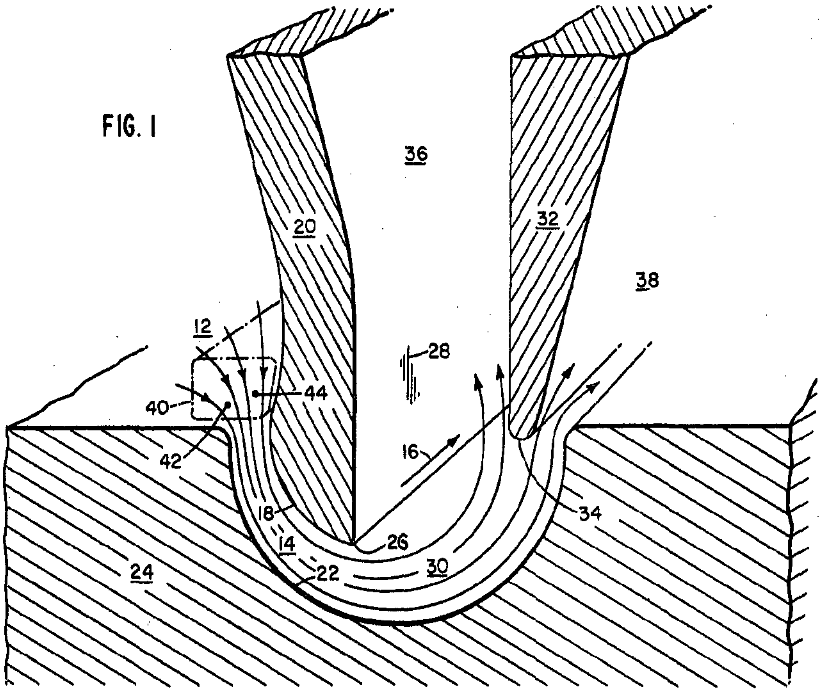

FIG. 2