ASP SEPARATION TECHNOLOGY FOR ISOTOPE AND GAS SEPARATION

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Abstract

The Aerodynamic Separation Process (ASP) developed by the private company Klydon, is a truly profound technology that presents a quantum leap separation performance enhancement, for isotope species or gas mixtures, compared to the genesis technology that previously existed in South Africa and France. As its name indicate the separation is in essence aerodynamic, therefore, the methodology and engineering concepts used to develop and further advance, explain and predict ASP technology separation performance, are those provided by the mature and frequently used discipline of aerodynamics. These concepts typically rely on the mass difference in two isotopes of an element, or the molecular mass of gas molecules to separate the two isotopes or two gas components, and also on the molecular structure of the volatile compound used as process gas.The current status of ASP is based on the comprehensive study and experimental observations on many gas and isotope systems.

Keywords: *aerodynamic separation, stationary wall, ASP, isotope separation*

Introduction

ASP is Klydon's proprietary technology for separating components of a gas mixture or different isotopes of a specific gaseous compound based on the mass difference and molecular structural differences of the gas components or the isotopes. This is achieved by a high-speed centrifugal rotation of the gas or isotope mixture in a contained separation device where the process gas is injected through the stationary wall of the container. Separation is obtained close to the geometrical axis of the container and the different gas flow fractions are harvested at the ends of the separation device. All centrifuge technology relies on small differences in the mass of selected isotopes to enrich (or deplete) elements. Traditional centrifuge technology employs a fast rotating mechanical vessel, but stationary wall centrifuge technology relies instead on high-speed gas rotation through a static separator, inside a static containment vessel. This greatly reduces the number of moving parts, lowering projected capital investment and operating and maintenance costs. ASP utilizes novel extensions to the genesis concepts of the stationary wall centrifuge that is in the public domain.

Genesis Technology

The ASP technology developed from genesis technology that was first detailed in the scientific media in the mid 1970s /1-3/. Adequate narratives can be found in patents and a leading reference for separation technologies, whilst an industrial scale enrichment plant for uranium was constructed utilising the so-called "stationary-wall centrifuge." The salient characteristics of the genesis technology can be collated:

- The geometrical dimensions of the separation device are relatively small; length approximately 100 mm and diameter 12 mm;
- Gas injection into the device is tangentially at the surface with equally spaced inlets;
- The separation performance per device is low and the harvesting of product and waste portions were inefficient, accordingly millions are required to produce at industrial scale;
- The cut of the device, i.e. the ratio of the product flow relative to the feed flow, is highly asymmetrical, which results in reasonable product enrichment but inefficient waste depletion in the desired isotope or gas specie;
- The mass through put per device is small and accordingly the specific energy consumption is very high; and
- The regime of pressure range where the separation device was operate resulted in substantial gas turbulence in the device that contributed substantially to the high energy consumption.

This type of separator also exhibited distinct advantages, e.g. it has no moving or rotating parts in the device and does not require specific material properties. Furthermore, the retention time of the process gas inside the device is very small; of the order of milliseconds.

ASP Technology

The development of ASP technology over the past 15 years culminated in a much more advanced device that can compete handsomely on an industrial and commercial scale. The schematic presentation of figure 1 serves to highlight the current state of performance and the understanding of several important features of such a device. In the ASP device the process gas after injection at the surface of the containment vessel follows a flow pattern that conclude in two mini-centrifuges around the geometrical axis of the separator as shown. Each of the centrifuges feed material that becomes separated in the radial dimension to the respective ends of the vessel where the harvesting of the portions is accomplished.

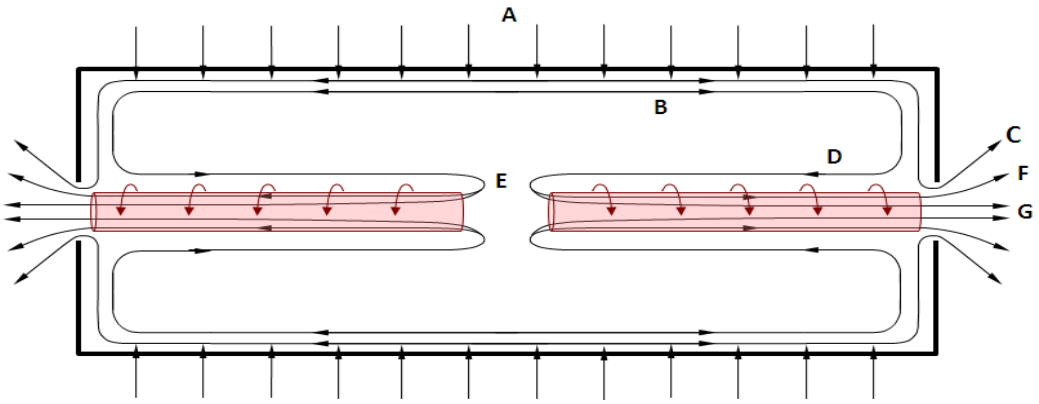

Figure 1. Schematic flow inside ASP separation device.

In the genesis technology period the extraction of a heavier isotope portion and a lighter isotope portion were accomplished by a single nozzle that intruded the opening at the vessel end, symmetrically placed around the geometrical axis as shown in figure 2.

The result of this configuration of harvest is a distinct feature of the genesis arrangement; the degree of enrichment that may be obtained has a clear maximum or ceiling value and any increase in the rotation speed has no further beneficial effect. This configuration also directly couples the enrichment factor and the cut; any increase in one parameter leads to a corresponding decrease in the other, which is an undesirable feature for a separation device. This ceiling value can be explained in terms of the Benedict formulism, after the lead reference edited by Benedict, that illustrates how the common mathematical description of centrifugal flow impacted by the geometrical limitation of the nozzle opening, when scanned in diameter, produces the combined effect of a ceiling value /4/.

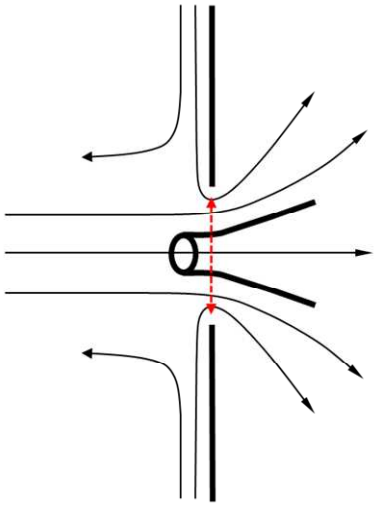

Figure 2. Extraction nozzle.

The ASP technology does not suffer from this limitation as it does not employ nozzles to harvest the product and waste portions; the detailed configuration is classified and protected under IAEA protocols.

An appropriate mathematical model describes the separation performance of the ASP device based on well known centrifugal equations. In figure 3 the description of separation factor, labelled as β, as the rotation speed is increased is depicted.

The ASP separator device exhibits no ceiling value in separation performance and theoretically this parameter can be very high.

In figure 4 two distinct features of ASP are show cased; the application is on the separation of silicon isotopes with atomic mass of 28 and 30, and the process gas is silane.

1. The experimental results clearly show that the enrichment factor for the device is decoupled from the cut as is the case for the gas centrifuge process.

2. The separation factors conveniently exceed the predictions of the Benedict formulism where the latter is the maximum that may be achieved by the genesis harvesting configuration.

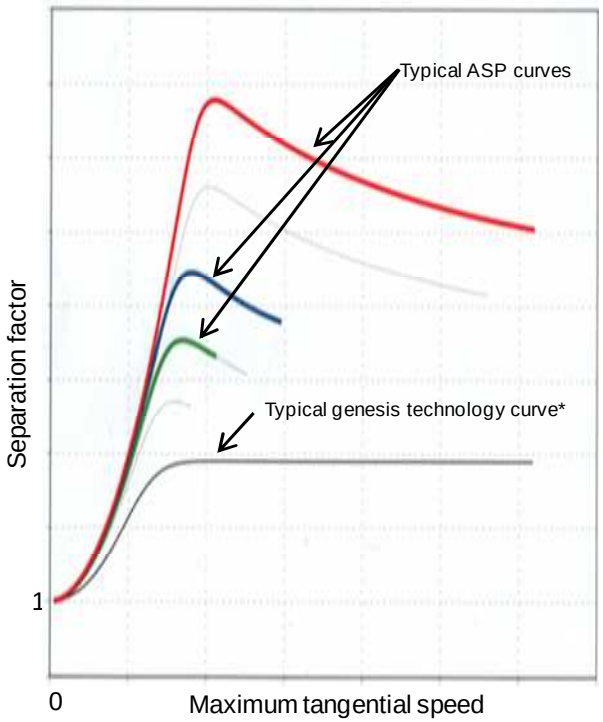

Figure 3. ASP enrichment vs. rotation speed; compared to Benedict formulation.

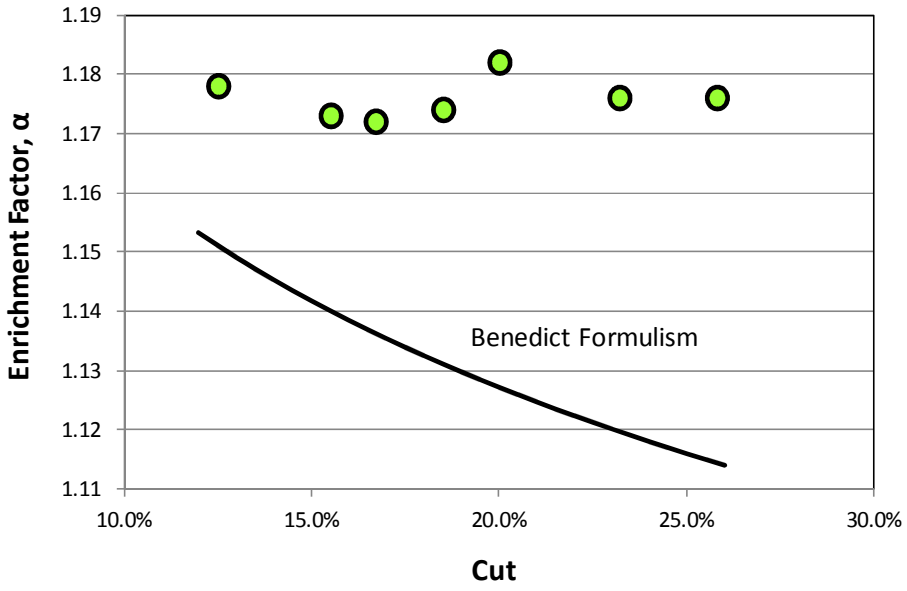

Figure 4. Enrichment performance of ASP device for Silicon isotopes.

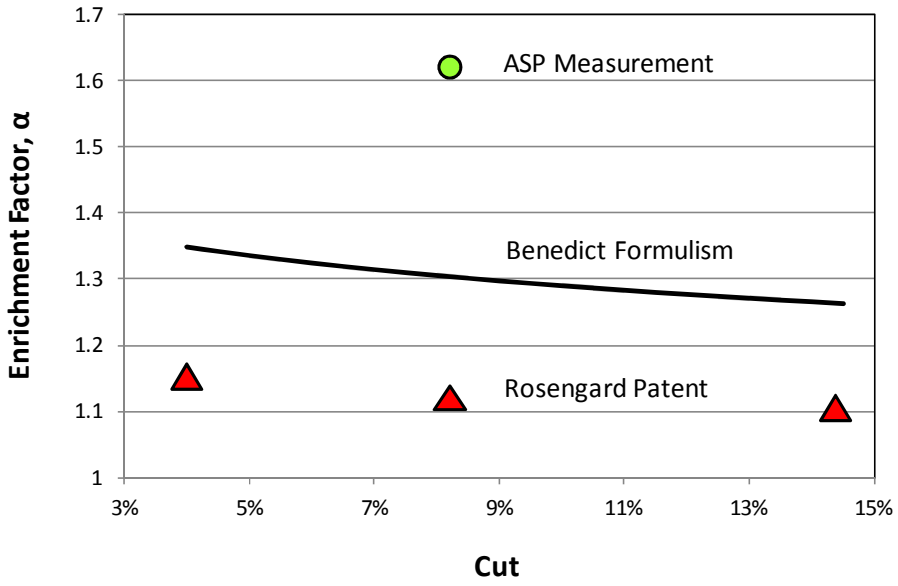

Figure 5. Separation performance for 4 mass unit difference isotope system at Argon mass.

Further evidence of the enhanced separation performance of ASP is presented in figure 5 in comparison with the results of the Rosengard patent for the isotopes of Argon /2/; 4 mass units difference for the two isotopes at mass 36 and 40. The lowest values for the separation factor have been copied from the patent results, whilst the Benedict formulism serves to reference the upper limit for the genesis technology. The operating conditions of the ASP device are the same as for the patent device, and the much increased separation performance of ASP is evident; the separation performance of ASP is approximately 100 times better for the lowest Rosengard experimental data, and approximately 80 times better than the highest experimental data.

Figure 6. Alpha Plant for silicon isotope production.

Klydon constructed a pilot plant for the production of silicon isotopes for application in the semiconductor industry to demonstrate the scalability of the separation device between laboratory and industrial level. It is a highly desirable feature of the ASP device that no performance scaling or enhancement is required for this step and the Alpha Plant confirmed this quality. The capacity of the pilot plant was 200 kilogram of 99.7% enriched Silicon-28 or the equivalent separation capacity of 1,000 Separative Work Units (SWU). The unit production cost was $4.3 per gram /5/ against a target cost of $5 per gram; our best cost prediction confirms $2.5per gram for 2,000 kilogram per annum capacity and < $1 per gram for 100,000 kilogram capacity. The silicon containing molecule is silane and the silicon content of this molecule is 87.5%, which is auspicious for efficient mass transport in the plant.

ASP has been under development over the past 10 years and the program moved progressively forward from the low atomic mass isotopes to mass comparable to that of uranium. ASP elegantly separates all the low mass (below 100 amu) stable isotopes that are important in the nuclear reactor industry, the healthcare market and the semiconductor field, as well as several applications in gas separation and cleanup:

- Hydrogen and Deuterium isotopes with an energy consumption lower than 4,000 kWh/kg that may be compared with approximately 12,500 kWh per kg /6/ for alternative process.
- Carbon-12 and 13; nitrogen-14 and 15; oxygen-16 and 18; boron-10 and 11; etc.
- Cleanup of natural gas or methane from unconventional sources at a cost of $0.5-1.5 per million British Thermal Units (MMBtu).
- The cleanup of biogas to harvest methane; capture of carbon dioxide from the flu gas that exits from fossil power stations; cleanup of shale gas from “fracking”; harvesting of hydrogen gas for fuel cell and energy production; and numerous gas separations in chemical industry.

The separation performance for ASP for the isotopes of oxygen that is important for Positron Emission Topography (PET), a fast growing healthcare diagnostic technique, can be placed in perspective relative to the existing technologies. Oxygen isotopes are currently separated by several versions of distillation and the crucially important parameters of enrichment factor and cut serve to illustrate the difference: in water distillation at boiling point the enrichment factor is 1.0032 /7/, in cryogenic distillation of carbon monoxide the enrichment factor is 1.0008 /8/, in cryogenic distillation of nitric oxide the enrichment factor is 1.046 /9/, and in cryogenic distillation of oxygen the enrichment factor is 1.0052 /10/. ASP can separate the oxygen isotopes, using oxygen gas as process medium, with an enrichment factor of 1.18 at a cut of 25%, and accordingly the separation performance is more than 3,000 times improvement /11/ on water distillation the current preferred technology.

The chronological and stepwise progression in the understanding and development of ASP technology is schematically illustrated in figure 7. A crucial tool in the mathematical account of the separation process, was establish that proved to be indispensable to fully understand ASP. Several parameters are included in the model that was not previously considered by the genesis version; amongst others the geometrical structure of the molecular specie is important.

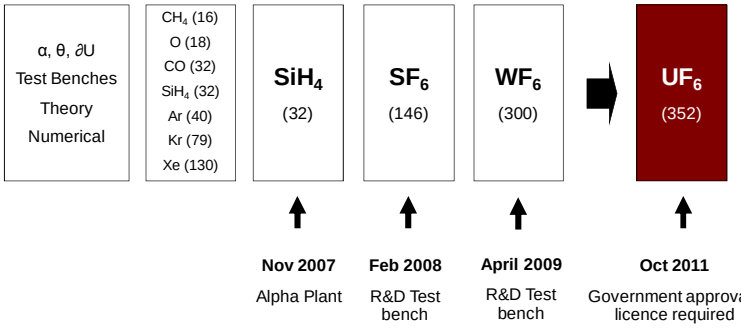

Figure 7. Chronological progression of ASP technology.

The application on uranium separation has not yet been demonstrated as a nuclear license is required to proceed to this phase. The results on the tungsten hexafluoride system are a good proxy for uranium enrichment augmented by the powerful predictive mode of the theoretical model that was verified over the mass range up to tungsten. Accordingly, a summary table (table 1) can be collated that reflects the current understanding if ASP is applied to uranium enrichment:

Separation Parameters	**Z-Plant 1985**	**Alpha Plant 2005**	**Alpha Plant 2009**	**SF_6 2010**	**Future UF_6 2013-2014**
Heads Enrichment Factor	1.027	2.08	1.1	1.1	1.15
Stage per Module	20 up 1 down	4 up 1 down	4 up 1 down	4 up 1 down	2 up 1 down
Mixing Losses	35-40 %	10-15 %	Low	Low	Low
Energy Consumption, E/dU (kWh/SWU)					
Separator device level:	1,800	1,400	466	500	~300
Overall Plant:	8,000	2,180			
Separative Work per Separator (kg SWU)	0.01	0.4	10	10	40

Table 1. ASP applied to uranium enrichment.

In table 1 the industrial plant called the Z-Plant constructed by the Uranium Corporation of South Africa (UCOR) serves as reference of the genesis era. The ASP separator device is 500 millimetres in length and the diameter is substantially larger than the genesis type device; such a device can produce 10 SWU per annum, which represents a 1,000 times improvement on the Z-Plant device. Note also that this level of separation accomplishment elevates the ASP device comparable to early stage gas centrifuge separators. The specific energy consumption for uranium enrichment is currently below 500 kWh per SWU, and the program foresees that this can be ameliorated to 300 kWh per SWU.

Perspective on Energy Consumption of ASP

It is a historical practise to preferentially quote the “operational energy consumption” of an uranium enrichment process to market its covetable commercial virtues; this is clearly an outdated practise in terms of contemporary policy on energy diminution and the global sentiments and protocols against carbon dioxide production and the global warming that it causes. An industry or commercial sector is presently labelled by its total energy footprint and the annual contribution to the production of environmentally unfriendly gases, and more specifically its carbon footprint.

The front-end nuclear fuel cycle is not excluded from these environmental criteria and ASP is accordingly merited in terms of total energy footprint; i.e. the energy expended from the onset of plant construction until the plant is dismantled and decommissioned (dust to dawn concept). The cost of construction materials that are normally included under capital expenditure are separated into an electricity component and the balance, which can be labour and resources. Per example it require 20,000 kWh per ton to produce aluminium, 4,000 kWh per ton of cement, and 3,500 kWh per ton of steel. Under the circumstances that an enrichment plant may require an elaborate foundation construction to isolate the plant equipment from seismic disturbances, the hundreds of thousands of tons of concrete, steel, cement, crushed stone, and the mass transport of these materials, add copiously to the energy footprint of the plant. During the operational phase of the plant it is customary to quote only the electricity that enters the plant via the electrical transformer, however, many examples of consumables contain a significant component of electricity. The cost of production of liquid nitrogen used to freeze out uranium hexafluoride in an enrichment plant is almost entirely for electricity consumption.

It is very important to develop a separation technology that can benefit from a low operational energy consumption, and equally important is the cost of electricity; i.e. minimum kWh per SWU and low $ per kWh. If the plant has diminished capital cost, which is the situation for ASP, several scenarios become available to “discount” capital for energy. The obvious scenario is to construct a electricity plant onsite and incorporate the capital cost with that of the separation plant. Klydon used USA prevailing cost parameters for electricity generation with natural gas, and illustrated that if the plant owner also constructs two power stations, i.e. double the enrichment plant requirement, to have continuity of electricity supply, of which he sells off half the electricity capacity, the electricity generation actually provides a net income. The cost of natural gas was varied from $4 per MMBtu to the breakeven cost of $13 per MMBtu; the current cost of natural gas is below S4 per MMBtu /12/ and the longer term prediction is $7-8 per MMBtu /13/. This mode of operation will also elegantly buffer the separation plant against future cost escalations in the electricity price.

In conclusion, the historical cited operational energy cost for ASP will not be lower than that for the current global reference technology; however, on a total energy footprint basis ASP can outperform the reference. Furthermore, the cost of operational electricity can be discounted into a net income and astutely buffered against future electricity cost escalations.

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