Laser Isotope Separation

Design and Development of Separator for Laser Isotope Separation of Lanthanides for Medical Applications

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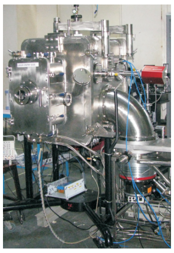

Separator for LIS

ABSTRACT

Beam Technology Development Group is involved in Laser Isotope Separation of lutetium, ytterbium and samarium isotopes of interest for medical applications. The technology is complex and requires integration of information and knowledge from various engineering disciplines, plasma and laser physics, atomic spectroscopy, chemistry and material science. The authors present here the philosophy and major considerations in the development of the separator chamber and its various subsystems.

KEYWORDS: *Laser Isotope Separation (LIS), Separator Design, Photo-ion Extraction, Multipass Optics.*

Introduction

Laser Isotope Separation (LIS) is one of the most promising but technically challenging isotope separation methodology conceived so far in the world. In LIS, precisely tuned lasers are used to selectively ionize a particular isotope of the feed material in atomic vapour form. The photo-ions are collected as product applying electric field (Fig.1). The LIS method becomes much more efficient than centrifuge when the isotope lies at the middle of the mass spectrum and a high enrichment is required. Additionally centrifuge requires feed as gaseous compound at room temperature. Hence, LIS is an attractive choice for producing Lu-176, Yb-176, and Sm-152 etc. with high isotopic concentration for medical applications.

The high vacuum process system consisting of the vacuum chamber and all its internal systems is commonly called the separator. High vacuum becomes a primary requirement for the process as the background pressure affects the formation of atomic beam, particle collisions and undesired neutral atom collection, charge exchange and ion collection, ultimately diluting the product concentration which is the major advantage of this process. Apart from the vacuum system, the other subsystems are atomic vapour generator, laser multipass optics, ion extraction system, gauges and monitoring instruments. The authors present some of the major aspects involved in the development of the separator system in the following sections.

Sizing and layout

The primary requirement for sizing is that the atomic source along with the ion extraction system should fit inside and are accessible. The chamber should be able to accommodate a vapour source of 400mm length and corresponding 450mm long photo-ion collector plates. Beyond this there are linear guide mounted laser beam apertures, thermal shields for protection of optics and space for connecting thermocouples. Along the height, the source to tails collector is approximately 400mm. Away from this; there is also a quartz crystal thickness monitor for online vapour flux measurement and space for electrical feedthrough.

The commonly used cross-section for pressure vessels is circular. However, the LIS system is slightly different. The aspect ratio of the processing zone is skewed as the requirement in the height and length direction is much more than the width. With this shape a circular section remains partly unused and increases the volume which leads to more load on the vacuum system. A cuboid system with an internal dimension of 600mm×550mm×750mm and double pivot fully openable doors at the front/back, providing clear access to the internals, is selected as preferred shape. The chamber is water

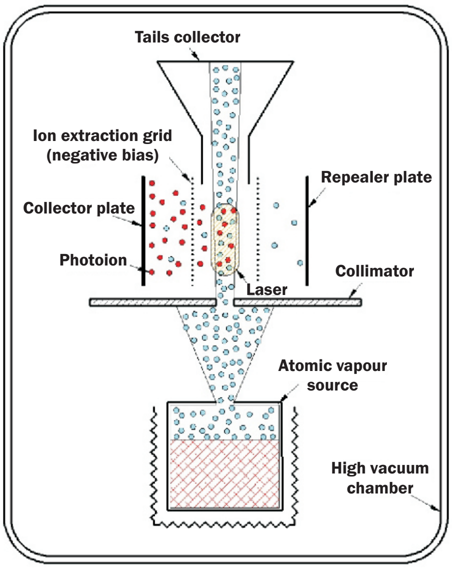

Fig.1: Schematic layout of LIS system.

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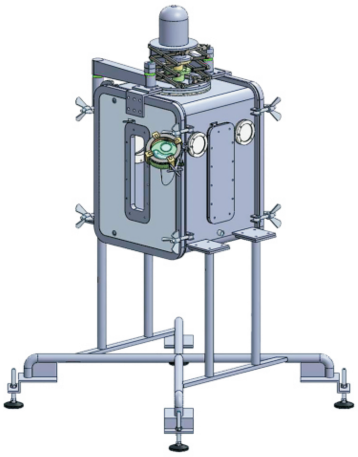

Fig.2: Geometric model of the separator.

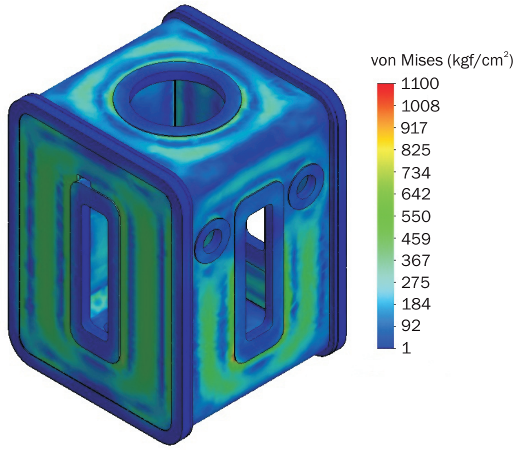

Fig.3: Stress plot of the chamber at severest load case condition.

cooled with cooling water jacket over the whole surface and has an internal volume of ~350L. There are eleven ports of DN-63 to DN-250 size and seven oblong ports catering to the vacuum system, gauges, monitoring instruments, electrical feedthroughs, optics and non-orthogonal viewing Fig.2 shows the schematic geometric model of the separator. The optics-ports are further connected to an optics-chamber which is detailed later. The overall chamber is made modular and the length of the chamber can be increased by addition of more modules.

Structural Design

A primary difference between the chambers with circular and rectangular cross-sections is the stress pattern. The rectangular geometry is guided by bending stress whereas the circular ones by membrane stress leading to lower material thickness and weight. However, for the rectangular sections as in current case, the specific advantages outweigh the increase in weight. From the requirement of weldable non-magnetic material, stainless steel AISI-304L is selected as structural material. In the present separator the 6mm thick inner shell is reinforced with welded square bars of 12mm×12mm cross-section. The jacket is 8mm thick. The design is carried out for the severest load case conditions comprising of the vacuum inside i.e. near zero absolute pressure, 4 bar gauge pressure of water inside jacket and 1.5 bar gauge pressure inside chamber for testing Fig.3 depicts the stress plot of the chamber.

The reinforcements on the shell are also used as the water flow path for cooling the chamber. The reinforcement size and spacing has been optimized from structural and heat transfer coefficient considerations. The flanges of the chamber are integrated type without any neck/nozzle. Apart from making the overall chamber size very compact, these flanges also provide stiffening to the shell and jacket. Although the ASME boiler and pressure vessel code, Section VIII, Div-I, Appendix-13 provides guidelines for design of noncircular sections, the present design is carried out primarily by first principle calculations and FEM analysis.

Thermal hydraulic analysis

The thermal hydraulic design is carried out to optimize the pressure drop in the flow system and the flow velocity hence heat transfer. The present design with nominal flow channel dimensions of 26mm×12mm can cater to uniform heat flux equivalent to ~20kW. The cooling water temperature rise is limited to ~18°C at 16lpm flow. Fig-4 shows the design curve for the shell of the chamber.

Fabrication

All over the world there are many codes for design and fabrication of process vessels. Few notables among them are, AD. Merkblatter (Germany), BS 5500 (United Kingdom), EN-13445 (France), IS 2825 (India) and ASME Boiler and Pressure Vessels Code (USA). Among them the ASME Boiler and Pressure Vessels Code is more popular due to its wide applicability and detailed QA guidelines. The fabrication of the present separator is as per the guidelines of ASME Section VIII Div-I, Section V and Section IX.

The overall flow of the fabrication was guided by the detailed QA plan. The flanges, plates and openings on the shell and jacket were made by water-jet cutting instead of conventional machining. Stainless steel being a poor thermal conductor, distortion of the welded section is inevitable even with proper stiffening and support. Stress relieving before removal of supports reduces the distortion. However, for most of the surfaces, keeping margin for further machining helped to maintain the dimensional requirements Fig.5 shows the integration of the water flow channels on the shell.

Chemical analysis of material, liquid penetrant test, ultrasonic test, radiography and hydro test were performed at various stages during fabrication. However the final acceptance was based on helium leak testing at 1×10^{-10} mbar.L/s sensitivity.

Vacuum system

The final product is used for human consumption as injectable, therefore, clean processing environment with minimum contamination is essential in LIS. A DN250 TMP with 1900lps nominal pumping capacity is used in the system with rotary pump backing for maintaining high vacuum. However the metal vapour in the processing zone, if swept to the high vacuum system, pose hazard to the TMP. Hence a vapour protection baffle is provided at the mouth of the TMP although it reduces the conductance and the pumping speed. The pressure is measured at two different locations with full range combination gauge, Penning and Pirani gauge. With proper

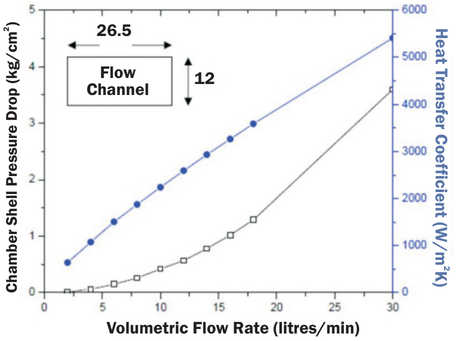

Fig.4: Thermal hydraulic design curve for the shell.

Fig.5: Separator shell with square bars as structural reinforcements and water flow channels.

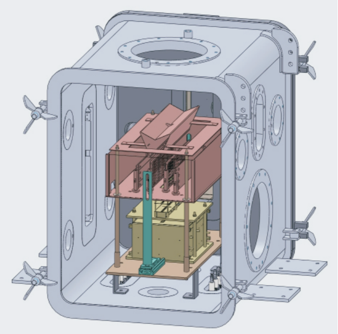

Fig.6: Schematic assembly view with vapour source, collimator, laser aperture and ion collectors.

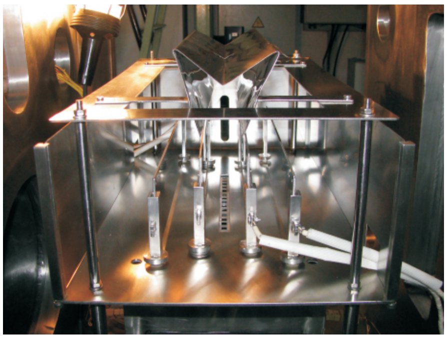

Fig.7: Assembly of electrostatic photo-ion collectors.

outgassing of the system, the chamber operates at baseline pressure of ~2×10^{-6} mbar.

Laser-Atom interaction and Ion extraction system

There are four major systems to be aligned inside the process chamber, i.e., vapour source, collimator, laser beam and ion collectors. The alignment and its repeatability become critical as any misalignment leads to a direct reduction in the efficiency of the process. As an example, misalignment of 1mm between the a laser beam of 10mm diameter irradiating a 10mm atomic beam leads to ~10% loss of product generation efficiency.

The laser-atom interaction and ion collection system is designed with a philosophy of guided manual installation. Each of the four systems is built from a single reference and the parts are aligned to the fit-up tolerance of the components leading to fast and accurate assembly (Fig.6 and 7).

Laser multi-pass Optics

The lasers used in the LIS system are routed multiple times through the processing zone. This is done by plane parallel mirrors place at the two longitudinal ends of the processing zone. If the multipass optics is placed outside the chamber boundary, there is an ease in operation but there is loss every time the laser beam passes through the optical window which becomes significant as the number of laser passes increases. Essentially this is loss of precious photon. This loss of laser power is avoided when the multipass optics system is placed inside the vacuum boundary. The mirror maneuvering becomes complex as the motions are controlled through stepper motors however the system has more laser power available at the processing zone. To accommodate the optics inside the chamber vacuum boundary, a separate optics enclosure is attached to the chamber which has separate door for independently handling the optics inside. The radiative heating of the optics box from the high temperature vapour source is minimized to protect the multipass optics housed inside. The optics boxes are optimized in size to reduce the volume addition as these are also evacuated though the main vacuum system of the chamber (Fig.8).

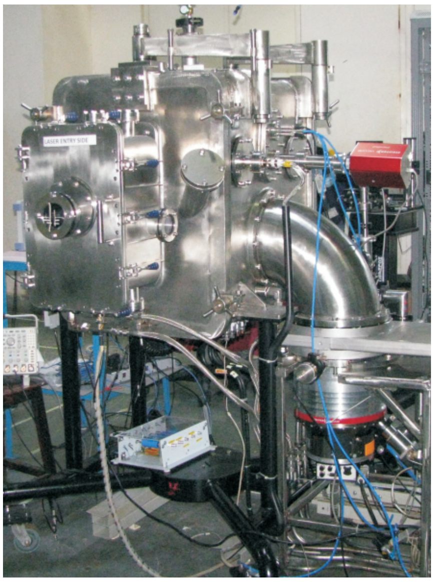

Fig.8: Commissioned Separator with external optics box and high vacuum system.

Conclusion

In conclusion, the separator development was a work of assimilating knowledge and ideas from multiple disciplines involved in the LIS work including various aspects of structural, thermal hydraulic and kinematic design, high vacuum design, handling of precision optics and ion extraction systems, design of high voltage system specifically to work with photoplasma. The system has been commissioned. It is being used for characterization of the separator internals and also for LIS experiments.

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