Letter from the CIS

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Potential for filtration and membrane technology for space industrialisation

Filtration and membrane technology will play a number of very important roles in the industrialisation of space. Here we look at some of the considerations and potential pitfalls in the transfer of these technologies.

The growth of interest in the industrialisation of space is not only explained by the increasing opportunities in the production of new materials, the realisation of new technologies, the solution of energy problems, and the utilisation of the moon's resources. It should be noted that space industrialisation will ultimately help to reduce human pressure on the Earth's environment. It is evident that in the near future nature conservation measures on Earth will be more expensive than the transfer of some kinds of industrial technology into space.

Thus, in deriving general concepts for space industrialisation, the following points should be considered:

☐ It is necessary to exclude the possibility of creating dangerous new anthropological effects on the planet as a whole. These may arise from changes in the functional state of the immediate space environment, as the result of its contamination by material and energy wastes.

☐ It is also necessary to minimise unreproducible losses of matter associated with its dissipation in space.

Thus, in this general approach to the industrialisation of space, it is timely to single out and analyse some of the particular problems regarding the possibility of using separate groups of processes, and their accommodation to the new operating conditions, since the involvement of many people in space industrialisation will demand fundamentally new approaches to integrated closed life support systems and to the organisation of industrial production. As a result, chemical technology and engineering will become an integral part of such space-based activities.

Chemical engineering systems used in space-based industry should satisfy the following requirements. They must be safe, compact, reliable, highly automatic, and highly efficient with minimum energy consumption. In addition, all systems should be closed, in order to minimise unreproducible losses of matter as well as avoiding space contamination.

The combination of severe technological requirements (some of which are given above) and the important distinctions of space conditions from those on Earth — namely high vacuum, reduced gravitation and hard radiation — make it possible to speak about significantly new trends in chemical engineering.

The available data show that one of the next century's problems will be the development of processes, apparatus and machines for chemical engineering which should be able to operate in extra-terrestrial conditions.[1]

Filter and membrane technology are of course already being used in space vehicle life support systems. However, a more general approach to the potential place of the above processes in space technology is needed.

These future wider opportunities for using filtration and membrane technology are determined by the following advantages: low sensitivity of processes to reduced gravitation; the possible accomplishment of several processes in one unit; susceptibility to external factors, such as magnetic, electric, thermal and other fields or forces which permit the intensification of a process; and the possibility of making completely automatic modules and cassette-type equipment etc.

Particular attention should be paid to the increasing role of porous media in keeping and monitoring material and energy flows in reduced gravitational conditions.

This discussion will be limited to considering the hypothetical possibilities of using filtration and membrane technology to monitor different kinds of material flows in certain problems.

Biomass synthesis on space stations by microbiology using monocellular seaweeds

The production and processing of biomass on a space station is a stabilising factor for space operations.

The use of biomass as an industrial raw material is attractive, as it reduces the problem of irreproducibility of some Earth resources, and allows production of a range of organic and inorganic materials by ecologically clean methods; also, concentration of some chemical elements by microorganisms reduces the 'enthropy ability' of material production. The high volume of biomass reproduction by microorganisms, however, gives rise to new potential sources of environmental contamination.

Here, a solution is to use membrane technology and partial filtration. Membrane technology at these industrial microbiological plants would be able to:

☐ control gas-exchange from technological systems with the environment, including liberation and concentration of various gas environment components (carbon dioxide, hydrogen, methane etc.) by selective membranes;

☐ control water exchange with the environment, including nutrient exchange, extraction and disposal of secondary products from the liquid phase;

☐ concentrate and extract biomass, returning it to a technological system of liquid phase and nutrients.

Membrane technology provides for process conditions that approach as close as possible to the level of organisation in living things, where all vital functions are accomplished via semi-permeable biological membranes.

The progress of biotechnology and investigations into biological membranes, leading to industrial membranes with controlled selectivity of the flow of material, energy and information — combined with intelligent monitoring by computers — will make it possible to create artificial, automatically controlled biosystems.

As space technology progresses, artificial self-organising biosystems under computer control will become an integral part of space- and moon-based stations. Membranes can control not only mass exchange of biosystems with the environment, but also exchange between individual subsystems, *e.g.* when the products of 'life' for one system serve as a nutrient for the other.

When producing extrapure biomaterials in a space station, membrane technology, microfiltration and normal-scale filtration may become necessary parts of systems for purification and sterilisation of the original media. ▶

intermediate and final products — as well as for protecting living media in a space station from the penetration of aerosol and gas contamination from the production zone. In these conditions of weightlessness, membranes and filters are the most acceptable basis for microorganism surface growth.

Semi-permeable membranes and microfilters are convenient elements for introduction and removal of components and products from a reaction zone during synthesis of new compounds in gas and liquid phase media, since the mechanism of their action is not practically affected by reduced gravitational forces, but rather determined by the laws of molecular and convectional diffusion. Further, membrane modules are highly compact — the mass exchange area of hollow filament membranes is 10,000 m^2 per m^3 of an efficient module volume.

Membrane filtration equipment can work under conventional conditions, since it does not require high levels of temperature, acceleration or vibration. There is no need to accelerate large masses, which makes its use in a space station very attractive.

It may be useful here to analyse the prospects of heterogeneous system separation by filters and membranes for industrialisation of the moon, and processing some of the non-terrestrial materials at a space station. The ways suggested now are based on two approaches: mining and subsequent processing of natural resources on the moon; and processing of raw materials on the space station, using the resulting product for construction of space-based technological and energy complexes, and the return of some of the product to the moon for its extensive industrialisation. According to some specialists' estimates, this latter approach would be more economical.[2]

According to Reference 3, a space-based complex would be able to process up to 300,000 tonnes of moon ore concentrate, producing about 20,000 tonnes of material a year, while the mass of a space complex itself would be only some 1500 tonnes.

Technology for moon regolite processing, in addition to thermal and electro-oxidation processes, would include grinding, magnetic sizing and filtration.[2] Oxygen and other chemical elements could also be recovered.

Regardless of where the raw material is processed — whether in a space-based complex or on the moon's surface, where there is no atmosphere — there is a problem of removal of excessive heat, large amounts of which are unavoidably generated during thermal processing of raw materials.

Where there is no heat exchange by convection, radiation heat exchange results in a sharp increase in the total mass of radiation coolers and the size of heat-exchangers. For example, in Ref. 4 it is noted that to irradiate 4000 MW at 1000K, the area of an absolutely black surface should be 70,550 m^2.

According to Reference 5, to remove 500 MW of heat produced during aluminium production, the surface area of radiation heat-exchangers should be 2 km^2. Depending on the material, a radiator's mass can reach 2 – 5 kg/kW. It is estimated that for a radiation surface area of 1 km^2 with a tube wall thickness of 0.2 mm, the rate of damaging impacts by micrometeorites is about 20 impacts per hour. Increasing the wall thickness reduces the number of damaging impacts, but increases the radiator's metal weight. Furthermore, to compensate for heat-carrier losses, an extra reserve of it would be needed on a space station.

The problem can probably be regarded from the point of view of combing hydrometallurgy and electrothermal methods of raw processing. Hydrometallurgy has been successfully developed to be reasonably efficient and selective, but, in order to separate dispersed systems and solutions, filtration and membrane technology can be recommended respectively.

These processes can be efficiently used at the enrichment stage. However, there is still the problem of maximised recycling of the liquid phase.

The use of hydromechanical processes when enriching raw materials from the moon, before sending them to space-based processing complexes, should reduce the cost of concentrate supply transportation. The concentrate can be bricked, frozen and transported in this form for further processing.

We shall now focus our attention on the advantages of the solid/liquid separation processes being considered.

First, as was noted above, they have low sensitivity to reduced gravitational forces, since they rely on the pressure drop and/or concentration difference. If necessary, however, these processes can be carried out in artificial gravitational fields (such as centrifugal fields).

Filtration equipment allows us to conduct several technological processes in the same piece of equipment: reaction processes with dispersed phases, filtration (solid phase extraction), washing (extraction), dewatering, drying. Because of the high vacuum in space, drying can be accomplished in sublimation conditions. The space vacuum can also be used as a driving force for filtration, if the partial pressure behind the filtration medium is maintained at not less than the suspension's solid phase boiling temperature; this makes the filter design simpler and more lightweight. According to experimental data obtained when vacuum has been used for air-tight cavity units in space orbital stations, a residual pressure of 0.1 Pa is practically achievable. There is now much experience of using vacuum filtration in various industries.

For thin cake layers or in agitated filter-driers, sublimated drying using the inner heat of the cake and filter — and, when necessary, by filter and agitator preheating — can be performed satisfactorily without a special drying agent. Sublimation drying is suitable for biological and high molecular weight materials.

The use of computers to control the operation of filter and membrane modules makes the process a highly automatic one, while increased magnetic, electrical and other effects on the systems being separated under weightless conditions make the control more flexible and selective. The use of robotised devices results in more stable links between system components, thus promoting its reliability.[6]

As well as producing semiconductor materials by carrier plasma vacuum spraying, some semi-permeable membrane elements could also be made in space stations using similar methods.

Porous filtration elements and membranes can play an active role in monitoring the separation by means of changes in their properties, *e.g.* mass, electrical or heat conductivity etc.

With some combinations of materials used to produce filtering elements and membranes, worn-out filter material can be reused — *i.e.* a worn-out filter of a higher purification grade can be used for systems where the purification requirements are not so strict.

Thus material used to make a filter is removed from purification systems with high requirements for separation quality, into systems with less severe requirements. Worn-out filter material can also be used in other systems as a porous or grain medium in a filter. For example, material from worn-out ceramic membranes can be used as a raw material to make fine purification filters, then a coarse purification filter, as a charge for deep bed filters; as a catalyst in the process of coating ceramics; as a filter for composites; or as a sublayer for the ground in hydroponics etc.

Under weightless conditions filtration can have another important characteristic — it can become a basis for making composites from the solid phase containing particulate dispersions and/or from emulsion fluids. This cannot be done under normal gravitational conditions, because of dispersion stratification, or as a result

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of the difference in settling rate of particles having different densities.

It is quite attractive to use filtration to produce composites from emulsified fluids with their subsequent solidification, or by encapsulating the carrier-extracted dispersed phase in a matrix. This idea has been prompted by results of the investigations made on the 'Skylab 4' space station.[7] Oil-in-water or water-in-oil emulsions without surfactant are a factor of at least 3.6 × 10^5 more stable under microgravity conditions than under normal gravitational conditions, while the coalescence rate is a factor of 3 × 10^6 less than the coagulation rate on Earth.

Undoubtedly many of the ideas presented here are already known, and some can be rejected point-by-point by space technology specialists. Nevertheless, it is a comfort that a rejected idea can bring new ideas to fruition.

More detailed analysis of filtration processes and membrane technology under weightless conditions may help to reveal new areas for applications. However, to move beyond general discussions to technical decisions, it is necessary to carry out detailed theoretical and practical investigations. At present there are many more questions than answers, including the following:

☐ What is the technical and economic value of hydromechanical separation using space-based technology, with different volumes of suspension?

☐ What should be the principles of producing the new filter materials, to allow their multiple use and efficient treatment?

☐ What should be the engineering solutions of industrial filters under weightless conditions?

☐ How to control the vacuum in the filtration process, and at the same time minimise filtrate, fluid and gas media losses during washing, drying and sublimation?

☐ What are the rules of filtration and cake properties under weightless conditions, when polydispersed systems under terrestrial conditions form sediments?

☐ How will the cake compressibility change if there is no gravitational sedimentation at all?

At present there are no criteria to determine the role and place of these processes in solving space industrialisation problems. There are no systematic ideas and engineering designs for the hydromechanical processes to be applied to the problem. Nevertheless, experience shows that filtration and membrane processes will play a significant role in space-based technology.

References

1. Asimov I.: *Chem. Eng. Progr.*, 1988, **84**, pp. 45–49.

2. Phinney, W.C., Criswell, D., Drexler, E. and Garmirian, J.: *AIAA Pap.*, 1977, **537**, pp. 1–10.

3. Grishin, S.D. and Leskov, L.V.: 'Space industry' (Nauka, Moscow, 1987), pp. 352.

4. Lukianov, A.W.: 'K.E. Tsiolkovsky and the problems of space production'. Preprints of XXI readings dedicated to Tsiolkovsky's scientific inheritance and ideas and their progress, IIET AN SSSR, Moscow, 1982, pp. 133–140.

5. Henson H.K.: *AIAA Pap.*, 1979, **1382**, pp. 1–7.

6. Lobachev, A.I. and Beregovoy, B.G.: 'Gagarin scientific readings on cosmonautics and aviation' (Nauka, Moscow, 1989), p. 246.

7. Leisy, L. and Otto, G.: *in* Steiga, L. (Ed.): 'Space technology'. (Mir, Moscow, 1980), pp. 351–361 (Russian translation).