A FACTORY CONCEPT FOR PROCESSING AND MANUFACTURING WITH LUNAR MATERIAL*

Gerald W. Driggers Research Engineer
Southern Research Institute
Birmingham, Alabama

Abstract

A conceptual design for an orbital factory sized to process 1.5 (10^6) metric tons per year of raw Lunar fines into 3.0 (10^5) metric tons of manufacturing materials is presented. A conservative approach involving application of present Earth based technology leads to a design devoid of new inventions. Earth based counterparts to the factory machinery were used to generate subsystem masses and lumped parameters for volume and mass estimates. The results are considered to be conservative since technologies more advanced than those assumed are presently available in many areas. Some attributes of potential space processing technologies applied to material refinement and component manufacture are discussed.

Introduction

A chemical process and component fabrication factory design concept was evolved during the 1977 NASA-Ames Space Manufacturing/Space Industrialization Summer Study. The purpose of the conceptual design was derivation of mass and power requirements to support a systems analysis of the postulated baseline space manufacturing scenario. The scenario set the production quantities desired in a mature, operational factory.

The basic concept of the factory is shown in Figure 1.

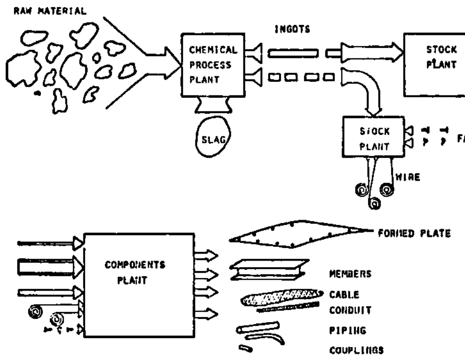

Figure 1. Representative Flow of Raw Material to Construction Components in Orbital Manufacturing Facility

The raw materials were assumed to be from the Moon throughout the study. The output is in the form of structural, electrical, etc. components which are subsequently assembled into the required product.

The conceptual design for the factory is such that a product need be specified only to the mass per unit and production rate level for purposes of mass and power estimates. It is, of course, necessary that the product materials comply with the constituency of raw material input. Alloying is generally allowed for assuming some mass input from Earth to permit basic material property variation.

The number of basic structural elements producible naturally must be limited in some fashion so that size, mass, power and/or productivity do not become driven or limited by variety. Allowance for plates, beams, tubing, wire, fasteners, films, blocks, pipes, joints and special components was made. Pressurized and unpressurized volumes for cutting, forming, fitting, drilling, joining, etc. were provided. A module for plant management, control and engineering requirements is also provided.

The technologies integrated into the concept are fashioned after existing facilities and machinery although the end-to-end concept (basic raw material to finished product) approach is slightly different compared to most Earth based industry.

Chemical Process Plant

The basis for the chemical process plant (CPP) portion of the design was data generated by the NASA-Ames study group on Lunar Resources and Their Utilization[1]. Their inputs to this conceptual design are summarized in Figure 2 and Table 1.

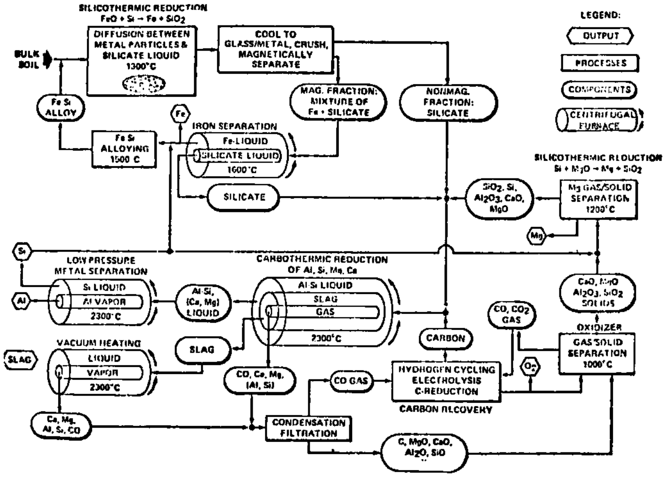

Figure 2. Process Concept for Lunar Soil

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Table 1. Chemical Process Plant Requirements Based on an Input Rate of 300,000 Metric Tons Per Year of Raw Material

ITEM	MASS (tons)	POWER INPUT (KW)	VOLUME (M^3)	HEAT OUTPUT (KW)	^{a}TEMPERATURE OF HEAT (°K)	RADIATOR MASS (tons)
Iron reduction system:						
solids processing	171	66	100	66	300	0.8
furnace/cooler	25	18,700	50	18,700	R	4.5
cent. furnaces/cooler	23	6,620	20	6,620	R	1.6
Carbothermic reduction syst:						
solids processing	29	17	25	17	300	0.2
furnace/cooler	224	150,000	300	5,100	R	1.2
Mg reduction furnace	15	17,400	30	300	R	0.1
Metal separation system:						
distillation furnace	74	73,700	300	0		
condenser	30	10	100	73,700	R	17.6
Carbon recovery syst:						
catalytic reactor	290	10	300	29,000	600	21.9
condenser/electrolysis	310	188,000	300	11,000	390	46.6
decomposition bed	13	10	20	31,000	R	7.4
Misc. and utilities:	181	361		361	300	4.4
Power plant:	1,820					
TOTAL	3,205	(454,894)		175,864		106.3
Total with radiators	3,311					

^{a}R = radiator limited - 800°K assumed

The items on Table 1. were arranged in a series of 15 meter diameter pressure vessels after linearly scaling the total capacity from 300,000 tons per year to 1.5 (10^6) Tons per year. The layout is shown schematically in Figure 3. Raw materials enter the system near Section A-A and aluminum, silicon, oxygen, iron and slag exit after Section D-D.

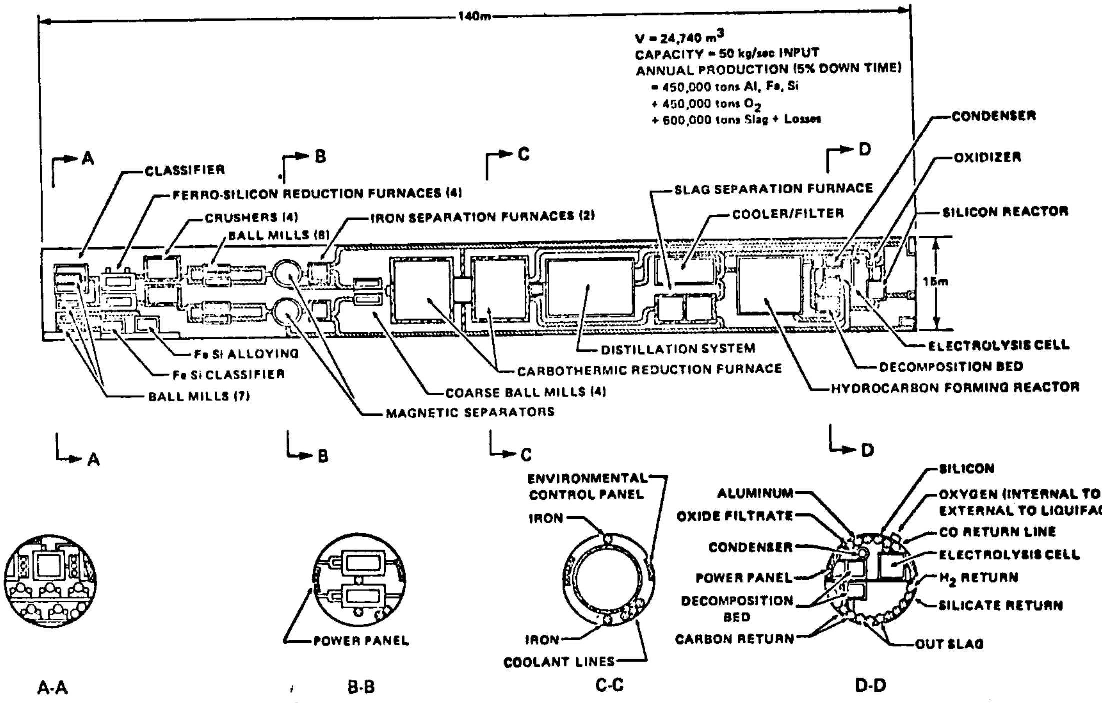

Figure 3. Schematic of the Chemical Process Plant Concept

Although higher productivity is predicted by theory, the plant was sized consevatively to produce 450,000 Tons of aluminum, iron and silicon, 450,000 Tons of oxygen and 600,000 Tons of slag (to be used as radiation shielding and construction materials). Linear scaling relations appear to apply to the plant at least from 300,000 Tons to 1,500,000 Tons input mass per year, thus allowing direct scaling of the plant parameters given in Table 1.

Manufacturing and Fabrication

After derivation of the materials through mechanical and chemical processing they may be routed to direct use (feldspar glass, silicon ribbon, cast slag, cast iron, etc.) or through an alloying process. The collection of modules shown on Figure 4 represents the generalized volume requirement for these activities based on estimates of specific volumes of machinery needed. No detailed design or analysis was conducted and basically continuous flow processes were assumed. Average flow for aluminum and iron would be about 30 Tons per hour, quite low by Earth industry standards. The alloying section provides elasticity in the flow of materials from the chemical plant to the manufacturing plant and ample time for alloying. Dwells of over 100 hours at a 30% volume utilization and 60 Tons per hour flow rate are easily accommodated. The two lateral modules were sized to accommodate about twice the anticipated flow rate of materials using machinery similar to that used in casting and drawing on Earth. The output of these modules would be direct use products as simple as cast pipe and as complex as finished solar cells.

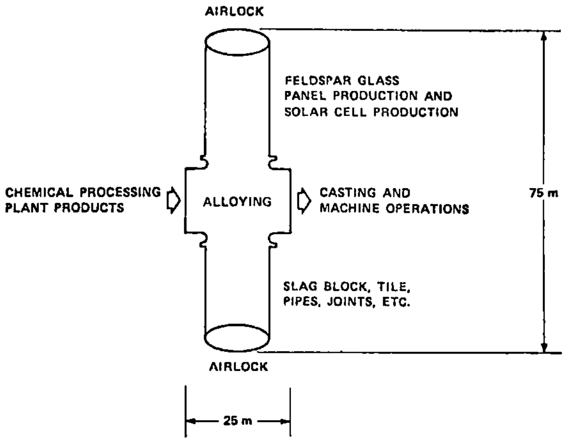

Figure 4. Alloying, Glass and Slag Processing Plants

The alloyed materials would pass from the center modules to the materials, components and section fabrication plant shown schematically in Figure 5. The casting system, rolling mills and large/small section mills were sized based on existing machinery with production capacity far in excess of the scenario needs in this study. In the absence of detailed design data on such machinery for zero gravity use, this conservative approach was considered the most appropriate.

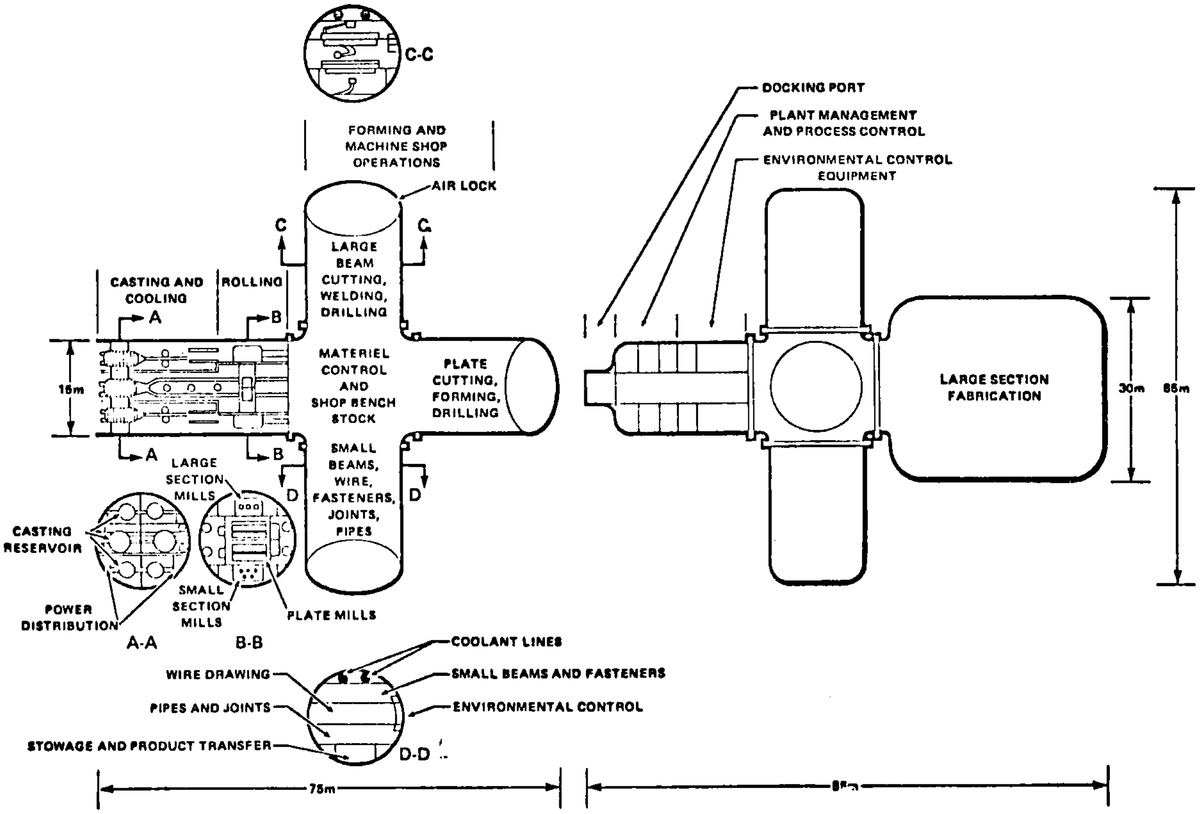

Figure 5. Materials, Components and Section Fabrication Plant

The remainder of this module collection is devoted to the manufacture of components, assembly and plant management. Volumetric requirements were estimated based on floor space utilization estimates for machines to perform the various functions listed on Figure 5. The number of specific machines of the various types cannot be determined until more detailed product designs are available. However, in the aggragate the volume allowed here should be sufficient to accommodate a rather broad mix of requirements.

The large section fabrication module is shown capable of housing under twelve psi of pressure a large segment of a satellite or habitat. Conceptually, the components of the segment would be laid up on a form and joined by fastening, electron-beam welding, etc. The module could be evacuated during joining if desirable.

Integrated Manufacturing Facility

The complete conceptual design resulting from the assessments described above is shown in Figure 6.

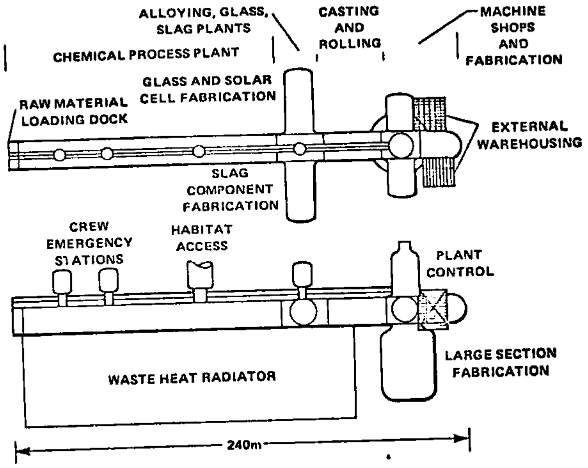

Figure 6. Two Views of the Manufacturing Facility

Added to the basic sections already discussed are: open frame external warehousing volumes; four personnel access tubes to control the flow of people; crew emergency stations capable of self-sustained operation for several days; a waste heat radiator; and a habitat access way.

Mass of the total facility was estimated using the specific data for the CPP given in Table 1 and a set of calculated lumped parameters. For the shell and structure a specific mass of 0.076 Tons/m was calculated for an internal pressurization of 12 psi. The density of internal components in the manufacturing modules was estimated to be between 0.10 Tons/m^3 and 0.20 Tons/m^3 based on Earth based machinery when working space and potential for weight reduction are considered. A specific mass of 10kg/m^2 was used to calculate the mass of the radiator (estimated to be about 80,000 m^2 in area). With the addition of personnel shafts, emergency stations and ancilliary equipment the total mass estimate ranges between 12,000 and 17,000 Tons.

Technology Impacts

The level of technology assumed in this conceptualization was intentionally kept at or near the present state of the art. Significant work remains to be done to factor in all of the potentials for use of the unique attributes of space, particularly very low ($\sim 10^{-5}$) gravity force levels and hard vacuum. Results from Skylab, ASTP and other space processing experiments indicate that novel material separation, refinement and alloying processes are possible. Also, such issues as how molten metals are handled in low-g must be addressed in the engineering sense. How light can fabricating machines be made? How fully can such a system be automated? These are two further examples of areas requiring more detailed analysis.

The purpose of the facility conceptualization presented here was to arrive at reasonable estimates of certain key parameters for input data into a space manufacturing systems assessment. The results not only have served that purpose but also provide a departure point for detailed studies and investigations of advanced technology benefits when applied to the systems. By Earth based standards the individual plants and segments are not highly efficient. Taken as a whole and coupled to efficient automated assembly outside the facility, the concept is very efficient in terms of manpower, mass and volume. The key is end-to-end, raw material to finished product system integration. The realization of this type of facility may represent the next plateau of industrial development.

References

1. Phinney W.C., et al, "Lunar Resources and Their Utilization" AIAA Progress in Aeronautics and Astronautics Series (in press).