PAPER NO. 7

ROLE OF METALLURGICAL PILOT PLANTS IN THE UNITED STATES(*)

H. G. Iverson,
Branch of Ferrous Metals and Ferroalloys,
Bureau of Mines,
U.S. Department of Interior,
Washington, D.C.

The large capital costs of metallurgical plants and rapidly advancing metallurgical technology have forced industry in the United States to rely increasingly on demonstration or pilot-plant investigations to minimize the risk of economic or technical failure of new installations. This commonly accepted use, which has been discussed frequently in technical journals, arises from several causes. Among these are the growing dependence on lower-grade ores or different types of ores than have been previously used, and on the increasing per-capita consumption of nearly all metals and metal-bearing products. Other reasons are the advent of new metallurgical processes, the need for new or higher quality products, and the availability of better equipment.

PURPOSE:

Metallurgical pilot-plant demonstrations show the way towards efficient operations and their principal function is experimentation to develop procedures for possible commercial use. Although limited research in obtaining some additional data essential to improving the procedures used is not excluded, this constitutes only a minor part of pilot-plant operations. Otherwise, it simply means that the processes are not ready for demonstration in this manner.

Pilot plants have two broad metallurgical applications. One is to reduce both technical and economic risks of new metallurgical operations, and the second is to improve technology and economy of all or some parts of existing practices. The purpose of these applications may involve primarily: Acquisition of data needed for scaling up equipment to commercial size; improvement of commercially used procedures; or acquisition of processing data in treating unusual type ores or in using new metallurgical processes. These applications may involve all types of metallurgical procedures that may be classified in the following categories:

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(1) Beneficiating ore to produce marketable concentrate;
(2) Leaching ore or concentrate and treatment of solutions to produce marketable products;
(3) Smelting ore or concentrate to produce marketable products;
(4) Refining mineral or metal products to meet market specifications;
(5) Shaping or fabricating metals and alloys.

Pilot-plant operations, whether they include one or more of these categories, provide data useful in determining design factors, and technical, operational, and economic feasibilities on which commercial operations might be predicated. However, selection for pilot plant demonstrations of any of these categories and of processes for them requires careful consideration of data prerequisite to designs and operations of pilot plants.

PREREQUISITE DATA:

Demonstrating by pilot-plant operations the feasibilities necessary to assure successful commercial applications can be costly in money and human endeavour. Experience has shown that for these investments to be made wisely some prerequisites to the use of pilot plants must be recognized. These prerequisites involve adequacy of data on:

(1) Ore deposits and representative samples
(2) Behavioural characteristics of raw materials.
(3) Quality of products and markets
(4) Processes and pilot-plant designs.

Ore Deposits and Representative Samples:

Establishing that adequate ore reserves are available, and that the estimated costs are favourable for mining and treating the ore on a contemplated commercial basis are major requirements for metallurgical pilot-plant demonstrations.

The detailed study of any deposit involves exhaustive investigations of geology; mineral and metal contents; size, shape and attitude of the ore body; physical characteristics of the ore and of the enclosing wall rock; and applicability of various mining methods. Size, grade, and mineralization of an ore body determined by sampling and careful study of geologic environment to assist in interpreting the data.

Obtaining and using samples representative of ores are essential to permit accurate evaluations.

Behavioural Characteristics of Raw Materials:

Laboratory research studies are directed toward finding the optimum ranges for processing variables. Depending on the processes used, the variables may involve: Nature of the feed; concentration of gases, chemical reagents or solid materials; residence time; rates of reactions; pressures; temperatures; solid-to-liquid-gas ratios; evaporation and condensation conditions; and thickening, filtering and washing conditions. The primary ends sought in these investigations include information on process requirements and on the principal processing variables. This information permits the selection of processes for pilot-plant demonstrations. Selection of processes, another important prerequisite for such demonstrations, takes into account recoveries of the desired elements or components in the form of marketable product or products.

Quality of Products and Markets:

Economic studies commonly made for conventional type products follow well-established patterns. However, for new or different type products, evaluation of potential markets is more difficult. One difficulty is estimating the degree or significance of user preference for the usual type products that might be competitive with the contemplated new ones. Another is estimating the length of time required to establish consumption levels when new uses must be found that would be adequate to sustain commercial operations.

Aside from market preferences, consumption, and competition, there are some factors that interrelate the costs of raw materials, prices for products and the optimum locations of commercial plants. Depending on the nature of the operation these factors may include cost of transportation, cost of electric power, or others.

Favourable economics for a contemplated venture indicated by comprehensive marketing studies constitute a major prerequsite for metallurgical pilot plant demonstrations and justify extensive study to select processes and pilot plant designs.

Processes and Pilot Plant Designs:

Preliminary research and economic studies may indicate a permissable choice of processing methods for pilot plant studies. For example, the research may indicate that beneficiating an ore produces a marketable mineral concentrate; that leaching an ore results in a higher quality metallic compound; and that smelting produces a metal or alloy of standard compositions. In addition, the preliminary work may show that either leaching or smelting can be applied to the mineral concentrate and that metal can be produced by electrolysis of purified leach solutions. To test all attractive processing possibilities in pilot plants could be very costly and, therefore, selection of optimum procedures usually is necessary.

Economic studies, together with preliminary research investigations, may indicate a marked superiority of a metallurgical procedure which may involve one or some relatively simple combinations of the foregoing methods. Such sharp guidance readily clarifies the selection of metallurgical procedures for demonstrations using pilot plants, and also simplifies somewhat the problem of designing the plants. However, designing is more difficult when economic and preliminary research studies do not clearly indicate superiority of any one procedure. In such instances virtually equal merits may be shown for each of several procedures or combinations of processes that perhaps involve more than one type of end product. Under these circumstances, a pilot plant is required with flexibility to accommodate more than one of the best procedures, difficult though it might be to design.

In addition to being designed for flexibility to permit conveniently the use of alternative methods, pilot plants should also be designed to withstand the rigorous conditions that may be imposed by the processes. Such conditions includes corrosion, high temperatures, high pressures, erosion, and so forth. Equipment exposed to such conditions can be expected to be replaced, perhaps frequently. Therefore, pilot plants should be designed to facilitate such equipment changes.

Metallurgical pilot plants must also be provided with adequate facilities for sampling and analyzing plant products, and with suitable instrumentation for controlling or measuring the important process variables. To permit making the necessary measurements, some process equipment may have to be specially designed to accommodate the needed devices. It is highly important that all significant data needed for evaluating the results and for designing commercial-size plants be obtained.

Selection of processes and basic designs completes the major prerequisites for pilot plant demonstrations. The next problems to be solved leading to pilot plant demonstrations are determining types and sizes or capacity and preparing the final designs.

SELECTION OF TYPES AND SIZES OF PILOT PLANTS:

Metallurgical pilot plants vary widely in capacity measured in quantity of feed or production per day. However, the desirable capacity of any pilot plant frequently depends on the purposes to be served, grade of feed, and unit value of the end product. If the purpose, for example, is examination of the leaching characteristics and efficiency of an existing commercial plant circuit, relatively small or even bench-scale equipment may suffice. But if the purpose is to appraise a new or different type of ore, a new process, or both, extensive pilot plant operations may be needed that begin with ore preparation and embrace all the steps necessary to make the final products. In such instances, the minimum size of a pilot plant is determined by the equipment with the largest capacity which may be the smallest that is practical for it. Such equipment items might include rotary, multiple hearth, electric or blast furnaces. But whatever this equipment might be, its practical minimum capacity determines the size of other equipment for a pilot plant of minimum capacity.

On occasion, pilot plants may be desired or needed which, in addition to being used for appraising new types of commercial ores or new processes also will serve the purpose of furnishing data adequate for scaling-up or designing commercial-size plants. In such instances, the minimum operable size of any equipment will not be the factor controlling the pilot plant capacity. Instead the governing item will be the equipment that presents the most difficult or severe problems in predicting operational characteristics when enlarged to a suitable commercial capacity. Reaction vessels and furnaces such as those just mentioned, usually fall in this category.

The complexity of physical, thermal, and chemical actions and reactions in most metallurgical processes precludes the possibility of attaining full operational similarity between either geometrically or linearly scaled models and the commercial-size units. Hence, often a model or pilot plant must be designed to permit evaluation of only those characteristics that constitute its most important functions. Characteristics for other functions must be corrected by judgment or by nearest-like experience, or relegated to a negligible role.

As one example, the most important function of a reverberatory furnace is to melt or smelt metals or ores. The shape and minimum size of a model of this type of furnace is governed primarily by the depth and area of the bath, its temperature and heat requirements, and combustion volume that accommodates the burning of a high heat fuel with sufficient heat release. The optimum model shape might tend toward a spherical configuration, different from that of industrial furnaces. Although the model or pilot-plant-size furnace may be admirably suited for its primary functions of melting, it is not suitable for studying other operational characteristics to extrapolate results to large furnaces. One example of the latter characteristics is heat loss which would be relatively higher for the model furnace than for the large furnace because of the larger area of the furnace walls and roof, per unit of volume of the furnace and of the molten bath. This in turn might cause the use of fuels of higher heat values and of hotter flame temperatures than needed in commercial furnaces, smelting, or melting similar materials. Another example of non-similarity is the difference in the effects on the refractories in a small-scale or model reverberatory furnace compared to a commercial-size furnace. The conditions imposed by the much greater weight of the molten mass and the greater erosive forces per square unit of refractory-bath interface in a large furnace cannot be approached in a small furnace. Hence, not from desire but from necessity, accurate determinations of extravagances or economies in heat and refractory losses, and of other characteristics, can only be made on commercial-size furnaces.

Model-size or pilot-plant-size rotary and shaft furnaces are also illustrative of equipment that can not be scaled up so that commercial furnaces are fully similar to the models in design and operation. Theoretically, the models can be designed to have similarities with large furnaces of the same types, in pressures, temperatures, retention time and gas velocities. This can be accomplished by reducing the cross-sectional areas but keeping the lengths or heights the same as for commercial furnaces. However, in retaining such similarities, the proportions of the model furnace would be impractical as a rotary furnace might be 2 feet in diameter and 200 feet long, or a blast furnace might be 4 feet in diameter and nearly 80 feet high. Here again models of these types of furnaces must be designed for the primary purpose they would serve.

Table I: - Iron blast furnace smelting; Comparative results with the experimental and a commercial furnace.

	Commercial furnace.	Experimental furnace
Coke rate, lbs./ton hot metal	1328	1344
Slag volume, lbs./ton hot metal	732	701
Slag basicity ratio, $\frac{CaO + MgO}{SiO_2}$	1.34	1.35
Metal, percent:		
Si	.55	.89
S	.049	.047
Production rate, tons/day	2185	22.8
Pressure drop, psi/ft. of burden height	.24	.27
Hot blast temp. °F	1500	2100
Wind Rate, cfm	100,000	1050
Dust rate, lbs./ton hot metal	110	75

The ratio of pig iron production 2, 185 divided by 22.8, or 96 was virtually the same as that for the wind ratio. Thus the latter was indicated to be a more appropriate ratio than the volume ratio 145 to 1 in comparing capacities between the experimental and commercial iron blast furnaces. However, perhaps more important was the similarity in the essential results which indicated the value of the experimental furnace data for interpreting or estimating the performance of commercial furnaces.

Other factors that govern the sizes of metallurgical pilot plants that employ a complete cycle of treatment from ore preparation to production of marketable products are grade of ore and the unit value of the component sought. Should the unit value of the recovered component be high, then a material containing only a few hundredths of 1 percent of this constituent might be potential commercial ore. To experiment adequately with such ores and to produce sufficient end products of consistent quality for use-testing a pilot-plant capacity of at least 10 tons of ore per day and probably much more might be required.

For concentrating ores that are used in large quantities but have low unit values, pilot plants of 2 to 5 ton ore capacity per 24 hours may be used. However, beneficiation plants of this size are limited to testing only some relative merits of various ore-dressing procedures measured chiefly by grade of concentrate and recovery.

When the concentrate must be agglomerated and smelted for complete evaluation, the quantities produced in these small plants are inadequate. As one example, complete evaluations in utilizing low-grade iron ore require large pilot plants for beneficiation. Investment by U. S. industry in such plants, including mines, is high; the cost of only one may be from 10 to 30 million dollars and may cost more than 1 million dollars per year to operate. A part of the high investment cost may be attributed to the provisions for evaluating technically and economically several methods of treatment, particularly in agglomerating the concentrate. This may include sintering on traveling-grate hearths, nodulizing in rotary kilns, or pelletizing, including firing the pellets in vertical shaft furnaces.

Pilot plants for low-grade iron ores in addition to being sufficiently large for furnishing products in adequate quantity for testing in commercial-size blast furnaces, have their size dictated by acceptable scale-up ratios. The proper annual capacity for a commercial plant may be deemed to be from 5 to 10 million tons of agglomerate. To be within a 20-to-1, scale-up ratio the pilot plant must produce about 250,000 to 500,000 tons of agglomerate annually. This quantity requires mining and beneficiating about 1 million or more tons of low-grade ore.

OTHER BENEFITS DERIVED FROM PILOT PLANTS:

Some benefits in connection with metallurgical pilot-plant demonstrations have been mentioned or implied. These include determining technical and economic feasibilities, the conditions that affect recovery and quality of products, marketing prospects, and factors affecting geometry of equipment and the design of projected commercial-size plants.

There also are other possibly significant benefits that may be derived from pilot plant operations. One of these is the opportunity for training personnel, including technologists and labourers. The use of trained personnel lessens the hazards for smooth operation of commercial plants when they are first placed in operation. Damages to expensive equipment are avoided, and contingencies that arise can be met more readily because of experience that the persons have derived from pilot-plant experimentations. Thus, shutdowns during initial operation of new commercial plants are minimized. Another benefit is that processing cost data can be obtained that permit estimation of operating costs for large plants. Such figures are one of the key items in deciding whether or not to venture into commercial demonstration or operation.

Pilot plants also afford opportunities drastically to change treatment systems at a cost much lower than if this had to be done in demonstration or commercial-size plants. Substantial changes sometimes are required in equipment and processes in commercial plants that use new processes or new types of ores. Such changes cause delays that are costly in production loss and in increased capital outlay. Adequate pilot plant experimentation before construction of commercial demonstration or production plants tends to reduce or eliminate such losses.

BUREAU OF MINES METALLURGICAL PILOT PLANT RESEARCH:

Much of the Bureau of Mines metallurgical research has been devoted to basic and applied studies, usually conducted on a laboratory scale. However, over a period of years the Bureau also has conducted many pilot plant investigations. One incentive for these has been the need for enhancing the U. S. supply of critical and strategic minerals and metals for emergency periods. Another has been the need for demonstrating the technical and economic feasibility of various processes that might be applicable to uneconomic raw materials, or which might have possibilities for providing superior type products compared to those commercially available. An additional incentive, when processes resulted in new type products, was the need for obtaining materials in sufficient quantities and of consistent qualities for evaluation by industry.

Prominent among Bureau pilot-plant investigations have been studies of iron, manganese, and chromium-bearing materials or ores, and development of processes for producing alumina, zirconium, titanium, and synthetic mica. Investigations on iron have included beneficiation of low-grade iron ores, preparation of sponge iron, and experimental blast-furnace smelting. Beneficiation techniques that were demonstrated have found use in commercial practices, and the significant improvements developed in experimental blast furnace smelting have been adopted in industrial operations.

In manganese research, the predominant studies have included beneficiation and leaching of low-grade manganese bearing materials and preparing manganese metal. The Bureau's process for making electrolytic manganese metal led to its commercial production in the United States. Pilot-plant investigations on chromium have included electric-furnace smelting of off-grade ores and electrowinning of chromium. A method for producing electrolytic chromium developed by the Bureau was further developed and used by industry, and electric furnace smelting studies conducted by the Bureau led to a small industrial production of ferrochromium. Similarly, the methods developed for making zirconium and titanium metals and synthetic mica also resulted in their commercial production.

Capacities of the Bureau's metallurgical pilot plants have ranged from a few pounds to as much as nearly 8 short tons per hour. The larger size plants usually were scaled-up models of smaller ones. However, the usual capacities were 0.5 short ton per hour or less in terms of ore or material being studied. The scale of some of the Bureau's work is indicated by data from selected pilot-plant experiments as given in table 2. The word "Ore" as used in this table does not necessarily mean commercial grade material. It is used in the table merely for convenience to indicate clearly only the metalliferous materials used and not total feed, which includes additive materials in some instances.

CONCLUSION:

In summary, pilot plants are accepted in the United States as necessary means to show the way for commercializing new types of metallurgical enterprises, or for improving existing ones. As each pilot-plant demonstration usually is designed to meet some unique problem each, therefore, may differ greatly from another one in design and capacity. However, there are some factors common to all that should receive careful consideration before or during the course of investigations. These include: Supply of resources of the material to be treated; suitability of markets in terms of quantity and quality of products that would or might be produced; adequacy of available technical processing data; availability of equipment suitable for the processes selected; recognition of the critical controlling process conditions and minimum practical capacity; and practicality of achieving similarity for the essential process functions in commercial plants.

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Table 2: Some Bureau of Mines Pilot Plants approximate capacities and results.

Pilot plant	Process	Short Dry Tons per Hour	Partial analyses, percent													
			Fe	Mn	Cr	Si	P	S	C	CaO	Mgo	Al_2O_3	Na_2O	K_2O	SiO_2	Percent Recovery
Iron	Tabling and flotation															
Ore		.1	36.1				.34			11.7		3.3			21.0	
Concentrate		.07	47.7				.36			9.4					8.1	91.5
Iron	Magnetic separation															
Ore		1.48	30				.002	.035							1.1	89.5
Concentrate		.56	70													
Iron	Smelting Blast furnace															
Ore		.646	56.9	1.02				.024		.54	.15	2.90			9.42	
Sinter		.16	61.2	.9				.010		1.70	.33	2.83			8.65	97
Pig iron		.49				1.64		.04								
Iron																
Sinter	Smelting-blast furnace	.275	54.6	.25				.12		.2	1.8	7.0			3.6	
Pig iron	a/	.163				.31		.045								97
Iron	Direct reduction															
Ore		.029	61					.18							13	
Sponge iron		.0152	71.4 b/					.24								84
Iron	Direct reduction															
Ore		2	50.8					.05							16.7	
Sponge iron		.94	[illegible]/89.5 b/				.085	.12							6	85 c/
Manganese	Flotation															
Ore		1	1.4	10.6			.04			2.7	1.3	8.0	1.8	3.5	54.2	80
Concentrate		.24	2.8	35.6			.08					2.6			16.8	

Table 2 (Contd.) - Some Bureau of Mines pilot plants approximate capacities and results.

Pilot plant	Process	Short dry tons per hour.	Partial analyses percent													Recent Recovery
			Fe	Mn	Cr	Si	P	S	C	CaO	MgO	Al_2O_3	Na_2O	K_2O	SiO_2	
Manganese	Flotation															
Ore		.05		17.9												
Concentrate		.022	4.8	32.6			.16			3.8	1.4	1.08			28.1	90
Manganese	Leaching-dithionate															
Ore		33		9.6			.05	.06		2.0	1.3	8.6	1.9	3.6	58.6	
Manganese oxide		.048	.2	59.6			.02			5.6	3.0	.1			1.4	91
Manganese	Smelting-electric															
Ore		.1	4.2	15.7			.14			3.3	1.3	2.61			52.2	
Alloy-Silicomanganese		.01	27.0	52		16.9	.52	.23								35
Manganese	Electrolysis															
Ore		.26	1.5	20				.46		2.8	2.7	7.5	1.1	2.44	33.0	
Metal		.041	.001	99.9				.03								80
Chromium	Electric smelting															
Ore		.119	9.58		17.9					2.55	21.6	12.0			16.8	
Ferrochromium		.029	32.6		55.9	3.82			7.01							75.3
Chromium	Electrolysis															
Ore d/		.009	12.4		27.1											86.9
Metal		.002														
Alumina	Leaching; lime-															
Anorthosite	soda-sinter	7.7								10.5		27.0	3.6		52.7	
Alumina		1.46										99.6	.32	.01	.081	70

a/ Sinter, .26% V, 11.1% TiO_2
Pig iron, .38%, V, .54% Ti
Slag, 20% TiO_2

b/ 98% reduced to metal

c/ Estimated

d/ 7.7% al; 9.63% mg.