Pakistan J.Sci.Ind.Res., Vol. 26, No.4, August 1983

OPTIMUM SIZE OF INDUSTRIAL AND MINI PLANTS: A RE-ASSESSMENT AND POSSIBLE GENERALIZED FORMULA

M. M. Qurashi

National Science Council of Pakistan, Islamabad, Pakistan

The Choice of technology for transfer to a developing country, or to a particular area or region in a developing country, involves a number of critical decisions, which include the type and size or capacity of plant. In a great many cases, the sophisticated technology can operate under the local conditions, but with a different capacity, while in certain other cases, an essentially different technology is found to operate more effectively under the local or village conditions. Mini-plants in general cover both these types of situation.

This paper first discusses a general formulation for the variations of cost of unit production, so as to estimate the capacity for optimum operation under a given set of conditions for some typical products, and gives a working formula for this. Then a discussion is also given of the merits of what may be called "micro-plants," based on an essentially different concept of village-level operations, using locally fabricated machinery and relatively unsophisticated designs. The products so obtained are eminently suited for local consumption and provide an incentive for rural industrialization so necessary for a balanced economic growth.

Several types of mini-plants, notably those for mini-cement, mini-sugar, mini-paper, mini-spinning and mini-fertilizer, have been extensively studied and appear to possess sufficient economic viability to justify field trials. The village-level operations for both cement and sugar seem to be feasible. Several others deserve R&D studies.

1. INTRODUCTION

The concept that the acquisition of sophisticated western technology offers a cheap and quick way to development for Third-World countries is one of the great myths of the present century. The Third World has learnt from experience that overall results have generally been poor; in fact the thoughtless transfer of sophisticated capital-intensive, large-scale technologies from industrial countries generally created more problems than it solved. Imported technology is by design adapted to very different basic conditions, such as relative shortage of labour, abundant supply of capital, cheap transportation and a large market, all of which tend to favour large plant sizes. It is, therefore, *not* surprising that these technologies in most cases turned out to be alien bodies in the new environments, where diametrically opposite conditions usually prevailed. Perhaps, as has been said, the final irony is that with all these costs – in dependency, in social and political impact and skewed development – the developing country does *not* even get the technology that it pays for. In the words of Dr. Martin Bell of UK, "Techniques are transferred and production systems are transferred, but technical knowledge is *not*. There is little transfer of the learning process." Imported technology, mostly large-scale, therefore, makes little contribution to indigenous capability building.

The *choice of technology* is the most critical collective decision facing the developing countries. It determines who gets work, it determines the infrastructure required i.e. patterns of educaton and training and the extent of national self-reliance or dependence on others. Therefore, the technology chosen will often be a compromise between the most efficient (large-scale) way of production, in a strictly technical sense, and a larger concern for the societal, and ecological effects of the chosen mode of production. Thus, the optimum choice will usually vary in type and size from country to country.

The large-scale technologies had been developed to suit the conditions of the countries in which these took root and then developed over a period of years. Therefore the developers of the particular technology, in attempting to recover the costs of development, try to sell their plants, irrespective of their actual suitability for other areas and environments. When such a technology is transferred to another environment differing from the one where it was developed, the chances are that the optimum size of plant will be different. So a study of this assumes considerable importance, especially for the developing countries where the costs of labour, raw materials, capital and transport are all different from those in the developed countries. Such an exercise is frequently important even in the developed countries themselves when there are large changes in the market or the price/availability of raw materials.

2. ECONOMIES OF SCALE RE-EXAMINED

A typical case is the introduction of paper-back books. As everyone in the publishing trade knows, there is a very definite optimum value for the numbers of a first edition for it to be profitable, and this is determined by the balance between the decreasing cost of printing a larger number and the maximum likely sale, which together determine the actual selling price of the hard-bound book. Actual cases tend to remain fairly close to the well-established maximum in the overall profit curves. However, if the book can be cheaply produced at say one-fifth of the price, then a tremendously larger market becomes available, and the *optimum solution therefore jumps from the existing maximum to a new maximum* at a much lower cost-and-profit margin, but with ten to hundred-fold sales, as in the paper-back editions of books.

Any successful technology is *optimised with respect to the various conditions prevailing* in the place where it was invented or first brought into operation. With the passage of time there may be improvements in the technology that enable more profitable operation, or there may be changes in some of the prevailing conditions. It has been found in the more highly industrialized countries, with rising labour costs and large export markets, that the larger manufacturing or processing plants are able to produce goods cheaper, and these economies have been termed *as economies of scale*. Thus the capital costs as well as the costs of operation do *not* vary linearly with the capacity of the plant, but may possibly vary as $(\text{capacity})^n$, where $n < 1$ (and may often be of the order of 3/4) so that the cost per unit output would vary inversely as $(\text{capacity})^{1-n}$. (Fi.g 1)

It has been found from experience (see Fig. 1) that, whereas the exponent 'n' may often be given as 0.7, in reality it may vary from 0.5 to 0.9 depending on capacity[1]. (The problem lies in the fact that the graph lines are *not* straight, but slightly curved, turning upward as the capacity increases, but n=3/4 is a good working average for this exponent). So that the reciprocal of cost per unit output would vary directly as $(\text{capacity})^{1-n}$, which would be of the order of $(\text{capacity})^{1/4}$, i.e. the cost is halved for 16-fold capacity, thus explaining the trend towards larger and larger plants.

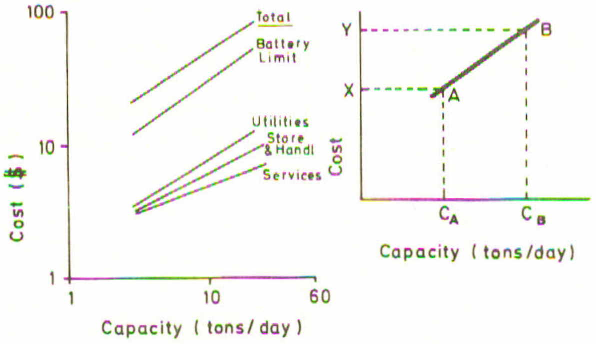

Fig. 1. Typical logarithmic cost-capacity diagrams for chemical plants.

Of course, this saving is ultimately offset by the costs of transport of raw material to the larger central plants and by the costs of marketing and management, among other things, so that the balance with these is the determining factor. Thus, it becomes necessary to take a fresh look at the currently acceptable optimum sizes for different types of processing/manufacturing plants, in order to determine the truly optimum sizes under various conditions and environments.

3. BASIC CRITERIA FOR OPTIMUM SIZE

The technology chosen will often have to be a compromise between the most efficient way of production in a technical sense and larger concern for the societal and ecological effects of the chosen mode of production, so that the optimum choice will vary from case to case. It must of course be made clear that *not all* capital-intensive modern technologies are in-appropriate for the developing world. For from it; often there may be no feasible alternative to these sophisticated technologies developed in the industrial world. These may offer significant advantages in the production of certain goods, such as nitrogenous chemical fertilisers, petro-chemicals, etc., that are essential for development. Again a country that seeks to earn foreign exchange by exporting manufactured goods to the industrialised world may also be forced to use sophisticated technologies to bulk-produce high-quality merchandise that can compete in international markets.

In general, it has been found in the more highly industralized countries, with high labour costs and larger export markets, that the larger manufacturing or processing plants are able to produce goods cheaper. Thus, the capital costs as well as the costs of operation do not vary linearly with the capacity of the plant, but (as indicated above in Section

2) may vary as $(\text{capacity})^n$ where 'n' is less than 1, and may often be of the order of 3/4.

Fig.1 is a sample set of log-cost vs log-capacity plots for a chemical plant[1], in which the factory "battery limit" curve may have a slope of 0.8, the utilities 0.6, the storage and handling 0.5, and the services <0.5. Specific knowledge of the individual cost patterns enables one to synthesise the total cost at any capacity, the total graph being curved. This relationship between manufacturing cost and capacity may in a limited range be approximated to by:

$$(\text{Cost}_B / \text{Cost}_{A_1}) = (\text{Capacity}_B)^n / (\text{Capacity}_A)^n \qquad (1)$$

where 'n' can now[1] be seen to have a most probable value of 0.7 ± 0.05. So cost/unit output produced would be proportional to $1/(\text{capacity})^{1-n}$,which is of the order of $1/(\text{capacity})^{1/4}$, thus explaining the fondness for larger and larger plants, c.f. the initial liner part of the plot of Fig. 2. for ethylene plants. In practice, this saving in production cost is offset by the costs of transport of raw materials to the large central plants and the costs of marketing and management, and other losses, and from the balance between these and other similar factors we can ultimately determine the optimum size. Thus, in Part I of series[2] of papers on mini-plants, after giving a general discussion of the factors that make it imperative to study the optimum size of various manufacturing/processing plants inorder to provide maximum benefits (under the particular set of conditions and environment existing in the place of application) especialy with reference to sugarcane processing, it was noted that mini-plants of 50 ton to 200 ton cane/day have a reasonable viability in regions far removed from towns and large mills, see also Fig. 5, (even though theoretically the reciprocal of the cost of production per ton varies approximately as $(\text{capacity})^{1/4}$).

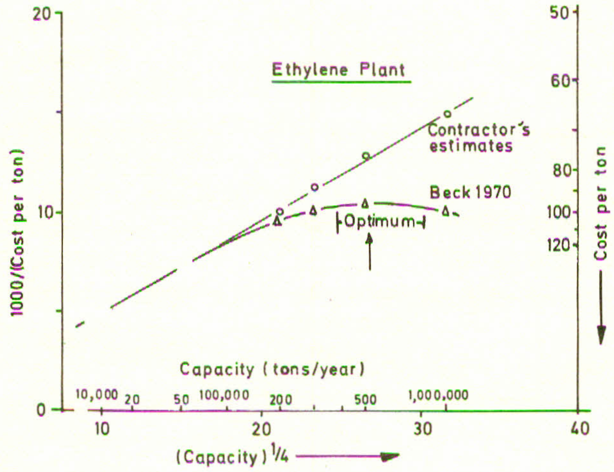

Fig.2. A plot of the reciprocal cost of production per ton against $(\text{capacity})^{1/4}$ for the ethylene plant estimates (hollow circles) and those modified by Beck (hollow 'triangles).

The oft-made assertion that larger the plant, lower are the costs[2], (cf Fig. 1), was first questioned during the early 1960's when critics of the concept argued that the economics of size had been *much oversold.* In Part II of the above-mentioned series[3], dealing with mini-cement plants, an interesting example was quoted from P.W. Beck [4] in respect of ehtylene plant cost-estimates. Using a reputable engineering firm's figures, Beck in 1972 applied his own critieria based on actual experience to obtain indices giving "a more realistic appraisal of the effect of scale for such installations." His results are summarized in Table 1 and the final indices are plotted against $(\text{capacity})^{1/4}$ in Fig.2, which shows that, under Western operating conditions, the production cost per ton actually *increases* with capacity *beyond* 500,000 tons/year, which thus represents the optimum size in this case.

The departure from linearity observed in Fig. 2 is particularly striking above a capacity of 300,000 tons/annum. It is the purpose of the ensuing analysis in the present paper to study quantitatively this departure in the three cases so far discussed viz. ethylene, cement and sugarcane processing, with a view to proposing a generalized basis for extrapolating to the optimum mini-plant from limited data in other similar cases, as also to examine the viability of the other category of village-level mini or micro-plants.

In general terms, we note that the total cost per ton of the product would be the sum of three components viz.

(i) Designed cost per ton,which is $\propto 1/(\text{Capacity})^{1/4}$;

(ii) Transport/Distribution/Marketing Cost per ton, which is roughly proportional to distance and so may be $\propto (\text{Capacity})^{1/2}$; and

(iii) Cost of losses during manufacture/transport, which may vary with capacity in a different way for individual cases, but may roughly be $\propto$ (capacity) or $(\text{capacity})^2$.

So combining the above three, we can expect the actual total cost per ton of product to vary approximately as

$$[A/(\text{capacity})^{1/4} + B_1 \times (\text{capacity})^{1/2} + B_2 \times (\text{capacity})^{1\frac{1}{2}}],$$

or as

$$[A/(\text{capacity})^{1/4} + B\,(\text{capacity})^{m}], \qquad 2\,(a)$$

where $\frac{1}{2} < m < 1\frac{1}{2}$. Here the second term always increases with capacity, as against the first term, which decreases as the capacity increases. It can be shown by differentiation that the total is a minimum at a capacity given by:

$$(\text{capacity})^{m+\frac{1}{4}} = \frac{A}{4mB} = \frac{(A/B)}{4m} \qquad 2(b)$$

4. ETHYLENE MANUFACTURING PLANT

Let us now take the data on the ethylene plant, as given in Table 1. Beck's correction factor can be interpretted as an additive correction to the manufacturer's estimates for production cost/ton, somewhat in the manner shown in Table 2, in which the capacity has been given in 10,000 tons/year for convenience, as $(\frac{\text{capacity}}{10{,}000})^{\frac{1}{4}} = \text{capacity}^{\frac{1}{4}}/10$. This additive correction, which corresponds mostly to transport and distribution costs, etc., can be seen by comparison with the first and last columns of Table 2 to vary approximately as the 5/4th power of plant capacity, being given approximately by:

$$\frac{15}{100} \times \left(\frac{\text{Plant capacity}}{10{,}000}\right)^{5/4} \qquad (3)$$

in a total of 100, cf. Beck's estimates. Thus, since the contractor's estimates are inversely proportional to $(\text{capacity})^{\frac{1}{4}}$, we find the actual production cost/ton to be given by:

$$\frac{\text{Production cost}}{100} = A \Big/ \left(\frac{\text{Plant capcity}}{10{,}000}\right)^{\frac{1}{4}} + \frac{0.15}{100} \times \left(\frac{\text{Plant capacity}}{10{,}000}\right)^{5/4} \qquad 4\,(a)$$

where $A \simeq 2.1$,

i.e.

$$A \Big/ \left(\frac{\text{Plant capacity}}{10{,}000}\right)^{\frac{1}{4}} \left[1+\frac{0.15}{100A}\left(\frac{\text{Plant capcity}}{10{,}000}\right)^{3/2}\right]$$

whence

$$\frac{100}{\text{Prod. cost/ton}} = \frac{1}{A}\left(\frac{\text{Plant capacity}}{10{,}000}\right)^{\frac{1}{4}} \Big/ \left[1+\frac{0.15}{100A}\left(\frac{\text{Plant capacity}}{10{,}000}\right)^{3/2}\right] \qquad 4\,(b)$$

Table 1. Analysis of economies of scale for ethylene plants (1972).

	Capital cost per annual ton		Production cost/ton	
Capacity of plant (tons/year)	Contractor's estimate	Beck	Contractor's estimate	Beck
200,000	60	84	100	105
300,000	53	77	89	100
500,000	45	69	78	98 (opt)
1,000,000	38	62	67	100

Table 2. Relative difference between contractor's estimate for production cost/ton and Beck's – for ethylene plant.

Capacity of plant (10,000 tons/year)	Contractor's estimates	Beck's estimates	Difference or correction	$(\text{Capacity})^{3/2}$
20	100	105	+ 5	90
30	89	100	+ 11	165
50	78	98 (opt.)	+ 20	353
100	67	100	+ 33	1,000

This gives the equation of the curve drawn through the plotted points in Fig.2 with a maximum at

$$\left(\frac{\text{Plant capacity}}{10{,}000}\right) = 50 \text{ which is}$$

$$\simeq \left[\frac{100A}{0.15\text{x}\,5}\right]^{2/3} \text{ as given by equation 2(b).}$$

5. CEMENT MILLS

(a) Sophisticated Rotary Kilns. We next consider the case of rotary cement kilns, which usually range in size from 100,000 to 500,000 tons per year, i.e. 300 tons/day to 1,500 tons/day. The cost per ton data (in the early nineteen sixtees) for these are shown in the following Table 3. It can be seen from the Table (and the corresponding Fig.3) that, whereas the fixed investment per ton varies *inversely* as $(\text{Capacity})^{1/4}$, the costs for transport and distribution, etc. vary *directly* as the $(\text{Capacity})^{1/2}$ approximately, being given by

Table 3. Estimated minimal fixed investment costs per ton of capacity appropriate to developing countries (early 1960s) for rotary kilns

	Costs/ton of product		
Plant capacity (tons per year)	Fixed investment (dollars per ton	Transport and distribution (dollars/ton)	Total dollar/ton
50,000	45-50	3	50.5
100,000	35-40	5	42.5
200,000	30-35	7	39.5
400,000	25-30	10	37.5

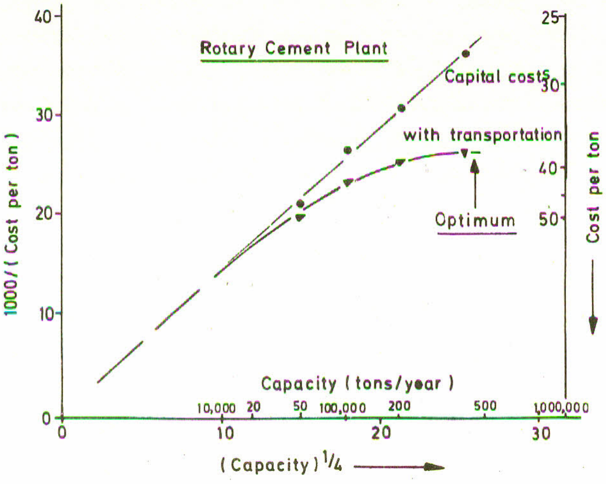

Fig. 3. A plot of the reciprocal cost of production/ton for the rotary cement kilns, including the correction for transportation and distribution (solid triangles).

$$1.5\left(\frac{\text{Plant capacity}}{10{,}000}\right)^{1/2} \qquad (5)$$

Taking the second column (fixed costs) as

$$70/\left(\frac{\text{Plant capacity}}{10{,}000}\right)^{1/4}$$

this yields for the actual production cost/ton;

$$\frac{\text{Prod. cost/ton}}{100} = \frac{70}{100}\text{ x }\left(\frac{10{,}000}{\text{Plant capacity}}\right)^{1/4} + \frac{1.5}{100}\left(\frac{\text{Plant capacity}}{10{,}000}\right)^{1/2} \qquad 6(a)$$

$$= \frac{70}{100}\left(\frac{10{,}000}{\text{Plant capacity}}\right)^{1/4}\left[1+\frac{1.5}{70}\left(\frac{\text{Plant capacity}}{10{,}000}\right)^{3/4}\right]$$

whence

$$\frac{100}{\text{Prod. cost/ton}} = \frac{10}{7}\left(\frac{\text{Plant capacity}}{10{,}000}\right)^{1/4} \Big/ \left[1+\frac{1.5}{70}\left(\frac{\text{Plant capacity}}{10{,}000}\right)^{3/4}\right] \qquad 6(b)$$

These relations are to be compared with equaions 4(a) and 4(b) respectively, and the maximum (at 500,000 tons/annum) again corresponds to the formula of eq.2(b), viz.

$$\left(\frac{\text{Plant capacity}}{10{,}000}\right)_{\text{opt}} = \left(\frac{70/1.5}{4\text{x}\tfrac{1}{2}}\right)^{4/3} = (23)^{4/3}$$

(b) Cement Mini and Micro-Mills. The foregoing analysis indicates a cost optimization for a rotary cement kiln with a capacity of around 500,000 tons, with only a ten per cent increase in cost at 100,000 tons/annum (300 tons/day). Hence the alternative vertical-shaft kilns have been considered for setting up of the mini-plants of this latter order of capacity i.e. 300 ton/day or smaller. New designs were developed, with continuous as opposed to

stationary operation, and were in use in Germany by 1940. This technology was developed on the basis of kiln design with daily capacity of 180-200 tons; 4-6 kilns of this capacity were installed in one unit, which thus became effectively a large cement plant. Improved vertical-shaft units have been established in all countries of the world, with the sole exception of USA. Certain recent developments include (see Fig. 4) the "Reba" technique developed by Readymix Cement Engg., Dusseldorf, and Scientific Designs (S'D) fluid-bed cement route, in which cost savings of about 30 % are claimed. The plant sizes range from 80 tons/day to 500 tons/day.

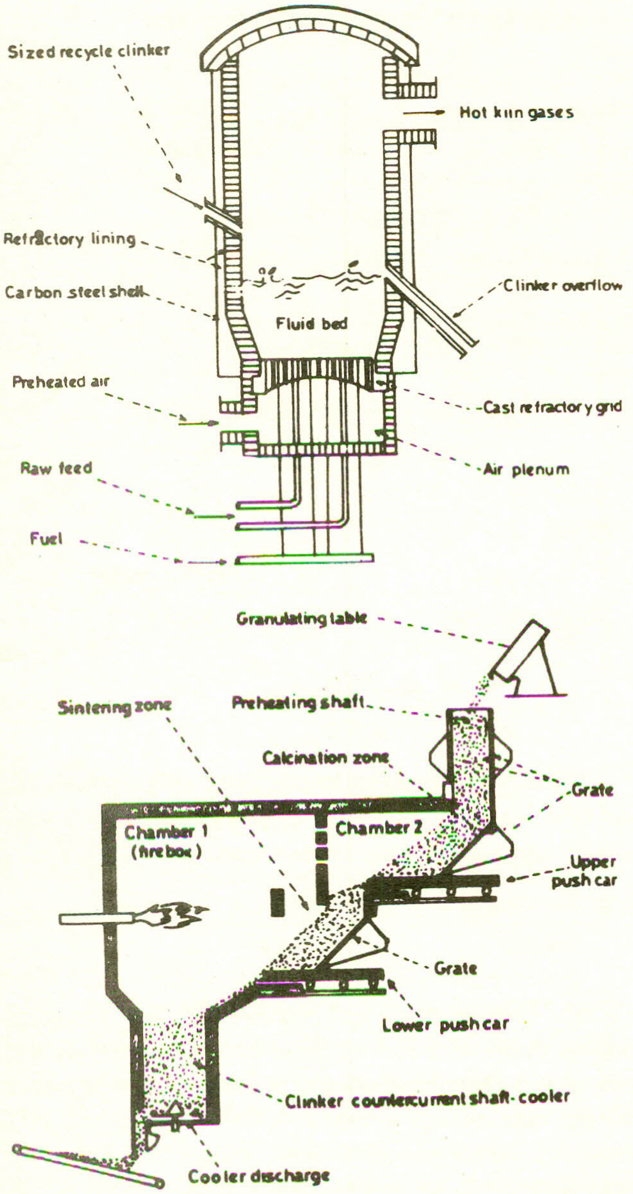

Fig. 4. Two typical designs for modern vertical-shaft cement kilns. (bottom) the "Reba" technique; (top) the S.D. fluid-bed design.

A most striking feature of the Chinese cement industry is the recent and rapid introduction of vertical-shaft kiln technology, which is used in most small-scale cement plants. The number of small cement plants, almost all of them located in rural areas, had increased from about 20 in 1965 to 2,800 in 1973[5]. The average *size of plants decreased* considerably – from about 25,000 tons per year in 1965 to 7,000 tons (i.e. 20 tons/day) in 1973. The small scale cement plants in China are basically serving localized rural markets.

The kilns in China's modern small cement plants – usually operated by counties or prefectures – generally have the following features:

(a) the feed is uniform nodules obtained from a simple disc noduliser; the kiln is fed more or less continuously by a team of men working on top of the kiln;

(b) clinker formation is confined to the upper portion of the kiln;

(c) draught is usually induced and heat-exchange takes place in the lower portion of the kiln; clinker discharge is usually discontinuous;

(d) fuel economy is good, because of
  i) fuel being interground into the nodules,
  ii) efficient heat exchange within the kiln,
  iii) porous clinkers, which need less energy for ginding; and solid fuels with higher ash-cement are often used.

There can be no doubt that the high transportation costs – in the absence of railways or water ways – have been a significant factor in the Chinese emphasis on local manufacture in relatively small plants, where the plant capacity has been chosen in order to match the market requirements of a county or part of a county. Recently, there are some indications that the Chinese experts are again considering cement plants of somehwat larger capacities than the above-mentioned mini-plants, possibly in the range of 18,000 to 60,000 tons/annum. The reasons for this changed thinking are:

i) 20 tons/day units require anthracite-too valuable a material for routine production of cement; *no other* fuel gives satisfactory results; hence these units are no longer under consideration for future cement plants.

ii) increasing Chinese concern about energy conservation.

(c) *Cement from Agro-Wastes:* Agro-wastes constitute an important raw-material for the production of cement and cement-like substances. Thus, for example, about one million tons of rice-husk are produced every year as a result of rice-husking in Pakistan, which are mostly discarded as waste. When viewed on a global scale, the amount of this waste is enormous. A simple low-cost incinerator has been developed by the PCSIR for burning rice husk, under controlled conditions, to produce rice-husk ash of the desired quality, which can be used to produce masonry cement. For large-scale production controlled heap burning is recommended; for which equipment and machinery could be fabricated locally[3].

Micro-Plant: Incinerator Burning. A used 45-gallon mild-steel oil drum (dia 22") was converted into a continuous incinerator. A grill (4 holes/in) was placed 6" above the base; two doors 8" x 6" were provided, one below and the other above the grill. The lower door was used for initially starting the fire and controlling the air draught, whereas the upper door was used for withdrawing the ash. A separate chimney with 4" dia window was provided on top of the drum. The process of burning is self-sustained and does not require any adjustment or control. The design of the incinerator was later modified by placing a wire gauze (4 holes/in) cylinder of 3" dia. in the centre; in order to supply more air to RH beds, another wire-gauze (4 holes/in) cylinder of 21" dia. was placed in the drum. This modification gave an incinerator temperature of about 700°C and the product was light-grey in colour with about 80 % activity.

Mini-Plant. Controlled Heap Burning. For large-scale production of RHA (5 tons/day), rice husk is burned in one or more heaps. In heap burning, the temperature should not be allowed to exceed 700°C. This is achieved by adding more rice husk on top of the heap to maintain the height or sprinkling water on it. The ash is withdrawn from the base when sufficient quantity accumulates.

Production of Masonry Cement from Lime-RHA-Surkhi: Two compositions, H (slaked lime 30 % RHA 70 %) and HS (slaked lime 30 %, RHA 50 % and Surkhi 20 %) were found satisfactory for semi-pilot plant production. The setting behaviour of these cements is similar to that of portland cement. Numerous tests have shown that the initial and final setting times are within BSS 12 limits.

6. SOPHISTICATED (V.P) MINI-SUGAR MILLS

It is especially interesting to reconsider the choice of technology and its optimum size for sugarcane processing in various areas of Pakistan. The interest on capital has risen to 15% and the capital requirements have increased from Rs. 90 million to 300 million for a 1,500 TCD Plant since 1970, giving a cost of Rs.2 lakh per TCD. Thus the annual "cost -of-capital" component in the balance sheet has increased 6 to 10 times during the last decade, as against 2 to 3-fold increase in the other items. Apart from that, there are other technical factors that tend to disfavour large scale sugar production in our country e.g the sucrose inversion due to the long haulage distances and waiting time before crushing (cf. Table 5, from IACP/PCSIR[6]) leading to a net sucrose recovery of 8.6 % ± 0.5 % by weight of cane, (see Table 4) and the ever-increasing cost of transportation. (The haulage time and waiting time leads to an average inversion loss of 2.5 % ± 0.3 % in the sucrose), as can be seen from the quoted recovery data as against a theoretical recovery of about 11 %, cf. Table 6.

Going on now to the cost analysis of vacuum-pan sugar mills reported earlier, we reproduce in Table 7 *the synopsis* of the complete analysis made (in 1981) for the operation of such mini-mills of capacities 150 TCD to 2,000 TCD under Pakistani conditions. The reciprocal of production cost/ton is seen to be given by

$$\frac{(\text{Daily capacity})^{1/4}}{21} \; / \; [\, 1 + \frac{(\text{Daily capacity})^{5/4}}{9{,}000} \,]$$

which is a maximum for a capacity of about 480 TCD, which thus represents the optimum capacity; Fig. 5.

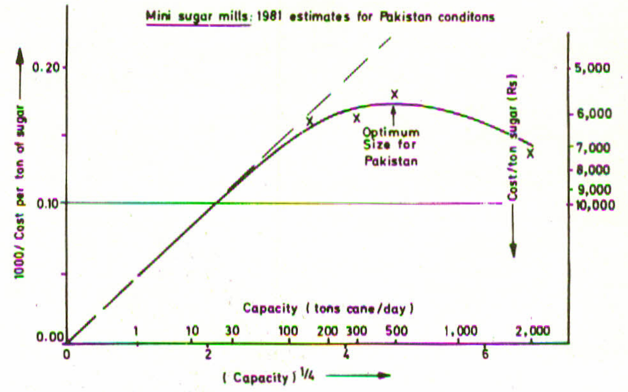

Fig.5. A plot of reciprocal cost of production/ton for Sugar Mills operating under Pakistan conditions.

Under present-day conditions in Pakistan, the data of Table 7 indicate that the most generally profitable optimum size may be between 300 TCD and 500 TCD for Vac.Pan Refined Sugar, as shown by the figures for 1000/ Cost of sugar per ton versus $(\text{capacity})^{1/4}$. It must be noted that the data of Table 7 shows that actual costs under Pakistan conditions, after taking account of inversion losses, haulage costs, etc., increase rapidly with increasing capacity. An interesting conclusion is that Mills of capacity

Table 4. Yearwise recovery.

1970-71	1971-72	1972-73	1973-74	1974-75	1976-77	1977-78	1978-79	1979-80
7.9	8.6	8.9	8.3	8.8	8.2	8.7	9.3	9.4

Table 5. Analysis of sugarcane haulage distance.

Mode of transport	Percent average by wt. of cane	Average Distance						
		Punjab		Sind		NWFP		Weighted average (in miles)
		Miles	%	Miles	%	Miles	%	
1. Trucks	49.5	50	45	30	54	5	100	21.3
2. Trolleys	34.5	20	43	15.8	26	–	–	22.7
3. Bullock carts	16.0	10	12	4	20	–	–	6.3
Weighted average		33		19		5		19.27

Table 6. Plant capacity vs. inversion loss and probable sucrose recovery.

Capacity	2,000 TCD	500 TCD	300 TCD	150 TCD
Inversion loss	2.5%	1.2%	0.9%	0.7%
Theoretical Recovery	11.1%	10.9%	10.8%	10.6%
Nett recovery	8.6%	9.7%	9.9%	9.9%

between 200 and 800 TCD seem to be more or less equally viable (cf. Fig.5). Accordingly, sophisticated mini-mills of capacity 150 TCD to 500 TCD are being marketted by some Danish[7] and German firms. Their capital costs are somewhat high, but their economy could be improved through local manufacture of many of the components.

7. OPEN PAN MINI & MICRO SUGAR MILLS

In addition, there has been considerable study of open-pan mini-plants of indigenous manufacture from 20-150 TCD, with sucrose recoveries of 7 % to 8½ % through successive crystallization. Clearly an optimum size has to be found, where the medium and small-size plant could be relatively efficient and at the same time generate employment of lower capital-cost per-work-place. For example, an Indian study tells us that an 80 TCD unit employs 171 persons, as compared to 900 by a 1250 TCD unit, thus generating 3.8 times more employment for the same amount of output. The cost per work-place is about 10 times higher for large-size plants as compared to small ones.

The accompanying plots in Fig. 6 (based on data obtained from various sources a few years ago (1978-79). show the variation for reciprocal cost/ton of the product for (i) the indigenous mini-mills (hollow triangles) and (ii) the village-level "belana" operation or "micro-mill" for making brown sugar or gur (hollow circles), which currently processes 60 % of the cane grown in Pakistan. It is seen that the mini-plants are economically viable in capacities from 50-150 TCD, while the village-level "micro-

Table 7. Comparison of cost of producing refined sugar under Pakistan conditions (1981) in mills of 150 TCD to 2000 TCD.

	Capacity of Mill	150 TCD	300 TCD	500 TCD	2,000 TCD
2.	Season length	160 days	160 days	160 days	160 days
3.	Estimated sugar recovery (taking account of inversion losses)	10.3%	10.1%	9.8%	8.6%
4.	Total capital cost (Rs)	24 million	41 million	57 million	320 million
5.	Operating costs (R. millsion)				
	Cost of cane	5.8	11.7	19.4	77.8
	Running cost	1.7	2.9	3.8	18.5
	Depreciation	2.0	4.1	4.8	32.0
	Interest	2.4	4.8	5.7	37.6
	Initial working capital	0.3	0.5	0.8	3.0
	Excise duty	3.3	6.7	10.6	37.1
		15.5	30.7	45.2	206.0
	Less price of molasses	0.4	0.8	1.4	5.5
	Nett cost =	15.1	29.9	43.8	200.5
6.	Sugar cost/ton at the present recovery estimated under (3)	Rs.6,200	6,150	5,590	7,280
7.	Probable effective selling price	Rs.7,000	7,000	7,000	7,000
8.	Profitability/ton of sugar	Rs. 800	850	1,410	(–280)*

(*) These would appear to be profitable only when subsidized, or if recovery is improved.

Table 8. Economic comparison of belana operation at 10 r.p.m. (3 units) with 20 r.p.m. (2 units) – 1980-81.

	3 units operated at 10 r.p.m.	2 Units operated at 20 r.p.m.	increase/ decrease	Monetary saving
Cane input/hour	0.5x3=1.5 ton: Rs. 390	1.0x2=2.0 ton: Rs. 520	–0.5 ton	Rs. 130
Juice output/hour	0.27x3=0.81	0.38x2=0.76 tons	+0.05 ton	Rs. 20
Maintenance, power etc./hour	Rs. 60	Rs. 40	Rs. 20	Rs. 20(–)
				Rs. 130

Note: Nett daily saving of Rs.1,300/- for a 10 hr day.

plants" can be a good proposition at capacities between 3 and 10 TCD. Some R&D work is going on in India to improve the performance of the mini-mills, while extensive R, D&E has been carried out on the power-belana as well as the animal-driven belana by PCSIR/Denver Research Institute in a project under contract to the Appropraite Technology Development Organization, Islamabad. Roll Design improvements have shown an increase of upto 10 % extraction of juice[8].

Typcial results for the belana operation at various roll speeds are shown[8] in Fig.7 and Table 8, from which it can be deduced that, while the maximum cane-juice per hour is produced at Roll Face speeds of 40-50 ft./min, this is accompanied by very low extraction of 40-45 % juice on wt. of cane. Therefore, a much more economically viable alternative is to replace two such power belanas by three machines operating at half the speed, thus increasing the juice extracted/hour together with an increased extraction of about 55 % by wt. of cane. An additional advantage of this operation is that brown sugar and gur retain many of the mineral constitutents of the cane juice and are therefore much less harmful for the body than white crystal sugar.

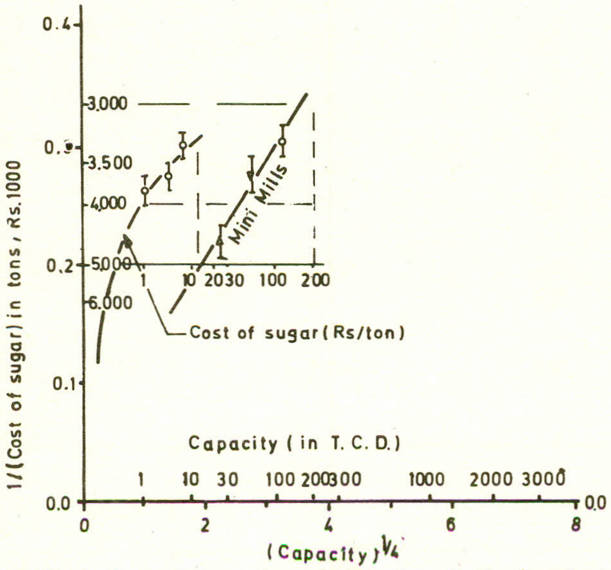

Fig. 6. Plots of the reciprocal cost of production/ton for indigenous open-pan mini-mills (hollow triangles) and village-level belana for gur making (hollow circles).

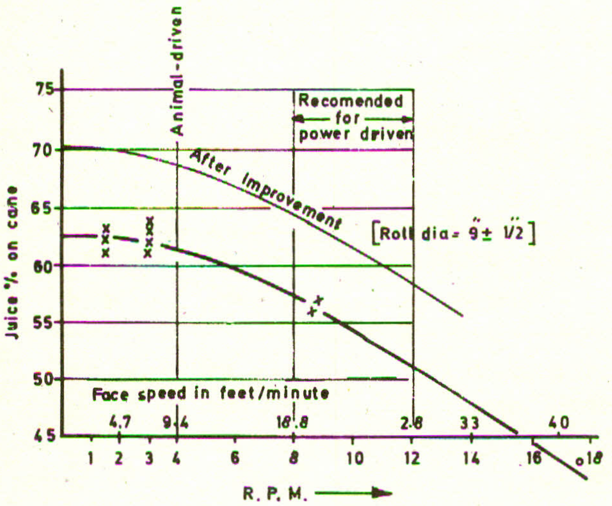

Fig. 7. Experimental curves for juice as % of sugarcane weight versus r.p.m. and roll-face speed for power crushers in Pakistan. The upper thin-line curve includes roll-design modifications.

8. CONCLUSIONS

The data of the above few examples of industrial mini-plants not only demonstrates the need for determining or estimating the optimum size of plants for the most economically profitable and socially beneficial operation, but also indicates how it can be done under the conditions and the environment that prevail in a particular locality or country. While the social benefits are difficult to quantify, it is possible to put down a generalized formulation of the economic factors using the main principles described above, as follows:

$$\text{Total cost/ton of product} = (\text{Design cost/ton}) + (\text{Distribution/ Marketing cost/ton}). + (\text{Cost of losses/ton}) \qquad (2)$$

Each of the three component terms depends on the capacity in a different manner. For simplicity, we may as a first approximation lump together the second and third terms into one, and write.

$$\text{Total cost/ton} = A/(\text{Capacity})^{1/4} + B\,(\text{capacity})^{m} \qquad 2\,(a)$$

$$= \frac{A}{(\text{Capacity})^{1/4}}\left[1 + \frac{B}{A}\,(\text{Capacity})^{m+1/4}\right]$$

where $\frac{1}{2} < m < 1\frac{1}{2}$.

The *three cases* of the ethylene plant, cement plant and mini-sugar plant are seen from the foregoing analysis of section 4,5 & 6 to fit this equation with values of m equal to 1¼, ½ and 1, respectively, and the values of B/A and m can be readily obtained from the data on plants of two different capacities. The plant capacity for optimum performance can then be estimated from the following relationship obtained by differentiating equation 2(a), i.e.,

$$(\text{Optimum capacity})^{m+1/4} = \left(\frac{A/B}{4m}\right) \qquad 2(b)$$

A similar analysis is applicable to the case of the village-level belana or micor-sugar plant, which has considerable potential for improvement. Among other processes in which mini-plants may have an economic future, mini-spinning units, mini-paper and mini-fertilizer deserve mention. Preliminary studies on these are being conducted in several developing countries. Studies on various village-level technologies need to be carried out in a systematic manner, so as to determine and utilize their potential for rural industrial development;

REFERENCES

1. C.A. Miller, "Current Concepts in Captial Cost Fore-casting" in Chem.Engg. Progress, **69**, (1973).
2. A. Wasay, M.M. Qurashi and E. Ali, Proc.Pak.Acad.Sci., **16**, 93 (1979).
3. M. Aslam and M.M. Qurashi, Proc.Pak.Acad,Sci., **17**, 85 (1980).
4. P.W. Beck, Chem.Engg., March 20, 1972, 45B-54D.
5. J. Siguardson, "Small-scale Plants in Cement Industry: Use of Vertical-shaft kiln technology in China", Economic & Political Weekly, 1974, 237-240.
6. (a) I.A.C.P. Report – "Evalution of Sugar Technologies in Pakistan" 1978.
   (b) P.C.S.I.R. Report – "The State – of – the – Art of Village-level Sugar Processing – 1978.
7. De Danske Sukker – fabrikker, Copenhagen, "DDS Small-scale Cane Sugar System – An appropriate Technology" at Presentation Symposium for the International Multilateral Aid Organizations, Washington, 1979.
8. M.M. Qurashi, S.I. Khan, A. Wasay, and Ehsan Ali, Proc.Pak.Acad.Sci., **18**, 139 (1981).