ChE classroom

TWO COMPUTER PROGRAMS FOR EQUIPMENT COST ESTIMATION AND ECONOMIC EVALUATION OF CHEMICAL PROCESSES

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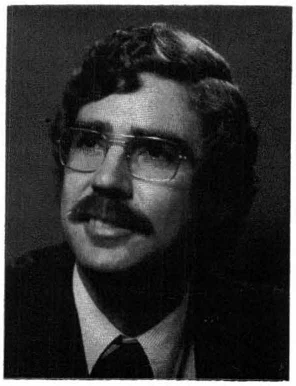
In recent years several cost estimation and economic evaluation computer programs have been developed, including those associated with ASPEN [2, 3, 4], Monsanto's FLOWTRAN [10], Purdue's PCOST [11], and others. However, the fact that these programs are not readily available to most colleges and universities motivated this work: the development of a cost estimation and economic evaluation computer program with the latest information in the field, easy to use and by all means suited to fulfill the requirements of a senior process design course.

The algorithms used for the cost estimation computer program were obtained from the ASPEN Project, eleventh, thirteenth and fourteenth quarterly progress reports [2, 3, 4]. These algorithms are based on cost data for 1979.



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EQUIPMENT COSTING PROGRAM

The equipment costing program is modular in design so that it is relatively easy to add equipment classes as new costing models are developed. It is also relatively easy to update the cost correlations for existing equipment classes without affecting other classes. A schematic diagram of the program modular structure is given in Fig. 1.

A feature of the general design that is worth mentioning is the procedure for handling input data errors. When an error occurs in the specifications for a given equipment item, the calculated cost of that item is the only one affected. In other words, the program can recover and continue to calculate the costs of the items that follow. This procedure is designed so that the program can detect as many input data errors as possible in a single run, as opposed to detecting one error per run.

Equipment Cost Correlations. The basic cor-

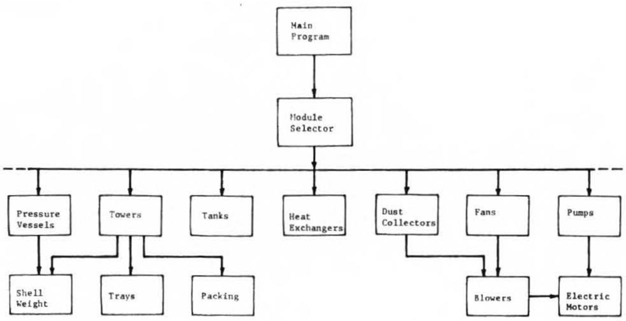

FIGURE 1. Modular structure of equipment cost estimation program.

relation for the base cost of a piece of equipment is usually of the form:

$$ln\, C_B = a_1 + a_2\, ln\, S + a_3\, (ln\, S)^2$$

where C_B = the base equipment cost per unit

S = the equipment size (or duty parameter) per unit

a_1, a_2, a_3 = the cost correlation coefficients.

The base cost is used as a basis to compute the actual estimated cost, the installation materials cost and the installation labor hours. It is usually the cost of the equipment in carbon steel for a common design type and pressure rating and thus independent of the equipment design type, the material of construction and the pressure rating. The estimated equipment cost is then calculated by the following formula

$$C_E = C_B f_D f_M f_P$$

where C_E = the estimated equipment cost

f_D = the design type cost factor (if applicable)

f_M = the material of construction cost factor

f_P = the pressure rating factor (if applicable)

If the equipment size is larger than the correlation upper limit, the function is extrapolated at constant cost per unit size

$$C_B = C_{Bmax}\,(S/S_{max})$$

where C_{Bmax} = the maximum cost of the maximum size

S_{max} = the maximum size for which the correlation is valid.

If the equipment size per unit is less than the correlation lower limit, the cost per unit is set equal to the minimum

$$C_B = C_{Bmin}$$

where C_{Bmin} = the minimum cost for which the correlation is valid.

Two computer programs have been developed which are suitable for use by students in process design courses. The equipment cost estimation program is flexible, easy to use and based on the latest cost correlations available, those from project ASPEN.

The equipment cost is adjusted to the specified escalation index in order to correct for inflation. The Chemical Engineering Fabricated Equipment Index [5] is used for this purpose.

Input Data Specifications. A sample of the input specifications for the equipment costing program is shown in Table 1. The data on this table illustrate the costing of seven different equipment items, organized in card-image (80-column) records. The first record of specifications for each equipment item is easily recognized by the asterisk (*) in column one. This code provides a key for the detection by the program of missing records or of records out of sequence.

Discussion of Cost Estimation Results. The results of the equipment cost estimation program for the items specified in Table 1 are compared in Table 2 with costs for similar equipment items that have been reported in the literature. Most of the literature costs are from Peters and Timmerhaus [7] which is a widely used text for process design courses. All of the literature costs have been escalated to a Chemical Engineering Fabricated Equipment Index of 259.9 (1979) for comparison. The agreement between the program

TABLE 1
Sample of Inpute Data for Equipment Costing Program.

```
                                   1979
*CDCK101DCCY     CYCLONE
 M3/SN/M2                          12          8.50 6.90E3
*CFAK102         INDUSTRIAL FAN     1
 M3/SN/M2                                      16.5 1870.
   K                               31                 323.
*CHEK103         HEAT EXCHANGER     3
 F2N/M2                            4          1000.1.034E6
*CPVK104PVHO     HORIZONTAL VESSEL  1
 FF                                              9.    30.
      F                                           .041666
*CPUK105         CENTRIFUGAL PUMP      2 1
 LBF3F3/'    N/M2                              62.4 47.472          6.9E05
*CTAK106 .I      FIELD-ERECTED TANK 1         1.13
 M3                                           1892.5
*CTOK107TOTR     TRAY TOWER         2
 FF                                2 3          14.   130.   75.
      F                                             0.20
*SUM
*END
```

costs and the literature costs is quite good in most cases and within the accuracy of preliminary study estimates. The largest discrepancies are in the cyclone and tray tower costs. For each of these cases the graphs in Peters and Timmerhaus had to be extrapolated, which may account for the discrepancy.

ECONOMIC EVALUATION PROGRAM

An acceptable plant design must present a process that is capable of operating under conditions that will yield a profit. The purpose of the economic evaluation computer program is to calculate two profitability indices: the net present value and the internal rate of return. These two indices are based on discounted cash flow techniques, taking into consideration the time value of money.

Net Present Value (NPV)

$$NPV = \sum_{k=0}^{n} \frac{NCF_k}{(1+i)^k(1+RINF)^k}$$

where NCF_k = the net cash flow for the k^{th} year

i = the effective annual rate of return

$RINF$ = the annual inflation rate

n = the number of years of duration of the project.

Internal Rate of Return (IRR). This is the rate of return that equates the present value of the expected future cash flows or receipts to the initial capital outlay. Normally a trial and error procedure or root finding technique is required to find the discount rate that forces the NPV to zero.

To be more realistic in the calculation of these two indices of profitability, the effect of inflation is included. Failure to at least try to predict inflation rates and take them into account can greatly distort project economics, especially at the double-digit rates that have become common throughout the world.

The procedure used in the program in computing the indices of profitability is described in the text by Bussey [1].

Economic Evaluation Program Results. Results of the economic evaluation program for a sample case are presented in Table 3. The problem is to estimate the profitability of a solids processing plant. Total purchased equipment cost is estimated at \$3,200,000, with an economic life of 10 years. An interest rate of 10%, inflation rate of 8% and

TABLE 2
Comparison of Equipment Cost Estimation Results

Equipment Item		Program Cost, 1979	Literature Cost, 1979	Reference
1. Cyclone	8.5 m³/s (18,000 cfm); 6,900 N/m² (28 in water); Excluding blower and motor	\$ 3,380	\$ 5,300	Peters and Timmerhaus [7], (p. 599). Extrapolation required.
2. Fan	16.50 m³/s (35,000 cfm); 1,870 N/m² (7.5 in water); 323°K (121 F); Carbon steel; Explosion-proof motor; Belt drive coupling	\$ 8,360	\$ 8,500	Richardson [9].
3. Heat Exchanger	1,000 ft²; 1.034•10⁶ N/m² (150 psi); Stainless 316; U-Tube	\$ 29,100	\$ 33,000	Peters and Timmerhaus [7], (p. 670).
4. Horizontal Vessel	1.034•10⁶ N/m² (150 psi); 9 ft diameter; 30 ft long	\$ 28,600	\$ 25,500	Pikulik and Diaz, [8].
5. Centrifugal Pump	6.9•10⁵ N/m² (100 psi); 62.4 lb/ft³; 23.74 ft³/min (178 GPM); Totally enclosed fan-cooled electric motor	\$ 1,830	\$ 1,800	AVS (American Volunteer Standard) Peters and Timmerhaus [7], (p. 557).
6. Storage Tank	1,893 m³ (500,000 gal); Carbon steel	\$ 79,600	\$ 71,000	Cone roof tank Peters and Timmerhaus [7], (p. 573).
7. Tray Tower	14 ft diameter; TTL = 130 ft long; Stainless 304; 75 Valve trays	\$859,000	\$657,000	Peters and Timmerhaus [7], (p. 768). Extrapolation required.

TABLE 3
Sample of Output Results for Economic Evaluation Program. Profitability.

END OF YEAR	NET SALES	OPERATING COST	GROSS INCOME	INTEREST EXPENSE	DEPRECIATION EXPENSE	NET INCOME AFTER TAX	SECTION 1231 CASH FLOW	NET CASH FLOW	PRESENT VALUE INCREMENT
0	0.	0.	0.	0.	0.	0.	-4404706.	-4404706.	-4404706.
1	13933488.	11581918.	2351570.	1027764.	2431999.	-576260.	-644883.	1210855.	934302.
2	17424176.	13894143.	3530033.	963276.	1958071.	316517.	-709371.	1565215.	931891.
3	21669312.	16668485.	5000827.	892339.	1576499.	1316634.	-780308.	2112824.	970621.
4	26790096.	19977360.	6812736.	814308.	1269284.	2459155.	-858339.	2870099.	1017369.
5	33256672.	24096912.	9159760.	728474.	1021936.	3852862.	-944173.	3930624.	1075074.
6	35917184.	26024640.	9892544.	634056.	822790.	4386562.	-1038591.	4170761.	880213.
7	38790544.	28106608.	10683936.	530197.	769855.	4879619.	-1142449.	4507024.	733936.
8	41893760.	30355104.	11538656.	415952.	769855.	5383481.	-1256694.	4896641.	615265.
9	45245248.	32783504.	12461744.	290283.	769855.	5928835.	-1382363.	5316326.	515431.
10	48864816.	35406160.	13458656.	152047.	769855.	6519112.	1001752.	8290718.	620221.

NET PRESENT VALUE AT 20.0 PERCENT RATE OF RETURN	3889614.
DISCOUNTED CASH FLOW RATE OF RETURN (PERCENT)	38.19
INFLATION RATE (PERCENT)	8.00
TAX RATE (PERCENT)	48.00

tax rate of 48% are specified. Base net annual sales are estimated at $22,634,000 with a fixed annual operating cost of $3,200,000 and a variable annual operating cost of $13,200,000 at 100% production. The variable annual operating cost is assumed to be proportional to the production rate. Percentages of production for the ten years of operation are as follows: 57, 66, 76, 87, 100, 100, 100, 100, 100, 100. Additional input data are the percentage of total investment financed by debt, 70%, the life of the loan, 10 years, and the depreciable life, 10 years. Depreciation is computed by the double-declining balance method with a salvage value of $320,000. The program input data are entered in free format.

The columns of the cash flow table (Table 3) summarize the major components of the cash flow for each year of operation. The numbers represent annual amounts in inflated dollars.

Case Studies. A series of results obtained with the economic evaluation program are summarized in Tables 4 and 5. The effect of inflation on the internal rate of return (IRR) and on the net present value (NPV) is illustrated in Table 4 for various financing and tax situations. Cases 1 through 4 represent "after-tax return" with a tax rate of 48%, while cases 5 through 8 represent "before-tax return," that is, tax rate equal to zero. The rest of the input data are the same as for the sample problem described above.

Comparison of cases 1 and 2 and of cases 5 and 6 show the effect of inflation on a heavily debt-financed project. The increase in both the IRR and NPV is due to the fact that the net income from the project inflates while the loan payments remain constant. In other words, most of the inflation losses are passed on to the financing organization. Comparison of cases 3 and 4 show that the effect of inflation on the IRR and NPV reverses when the project is 100% equity financed. This is due to taxes which increase with inflation

TABLE 4
Effect of Inflation on the Rate of Return and the Net Present Value

	Inflation Rate, %	% Debt	Tax Rate, %	IRR %	NPV @ 20% k$
1.	0	70	48	35.76	3,250
2.	8	70	48	38.19	3,890
3.	0	0	48	17.17	—1,580
4.	8	0	48	15.56	—2,400
5.	0	70	0	46.46	7,620
6.	8	70	0	51.17	9,180
7.	0	0	0	26.56	4,350
8.	8	0	0	26.32	4,130

as depreciation remains constant. Notice the negative NPV for both of these cases. This is because the actual IRR is less than the 20% rate of return used to calculate the NPV. The obvious advantage of debt financing in this problem is due to the low interest rate on the loan (10%). Finally, comparison of cases 7 and 8 shows that inflation has no effect on the before-tax return when there is no loan. This is because all of the remaining cash flow items are assumed to inflate at the same rate. Depreciation has no effect on the before-tax returns.

The effect of the depreciation method on the IRR and on the NPV is shown in Table 5. Both double-declining balance and sum-of-the-years' digits produce similar results and are superior to the straight line method. This is because the depreciation allowance is accelerated in the early years of the project reducing taxes and shifting after-tax income to the early years where it counts more. The double-declining balance method used by the program switches automatically to straight-line in the later years of the project as allowed by the rules of the Internal Revenue Service.

TABLE 5
Effect of Method of Depreciation on the Rate of Return and the Net Present Value

Depreciation Method	IRR, %	NPV @ 20% k$
Straight-line	34.22	3,300
Double-declining balance	38.19	3,890
Sum-of-the-years' digits	38.30	3,943

Percent debt: 70%
Tax Rate: 48%
Inflation Rate: 8%

CONCLUSIONS

Two computer programs have been developed which are suitable for use by students in process design courses. The equipment cost estimation program is flexible, easy to use and based on the latest cost correlations available, those from project ASPEN. The economic evaluation program frees the student from the tedious trial-and-error calculations which are involved in the determination of the internal rate of return. The program is realistic as it accounts for depreciation, income taxes and inflation. □

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