PROCESS ECONOMICS

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Contents

Summary

Chemical processes have been harnessed to transform resources and raw materials into more useful and hence more valuable products to improve the living standards of people. This principle is at the core of Chemical Engineering. These industries have

matured in the twentieth-century and have been very successful at creating wealth. The means of establishing which products to make and how to optimize the processes required for manufacture have been based on economic principles. This chapter defines how value is attributed to the material and energy streams that make up a process and then how this information is used to determine the economic value of options to ensure that optimum designs are reached. Approaches to accounting for the risks to the economic value of projects are also considered to ensure that they deliver the expected benefits. Once a chemical process plant is in operation there is an ongoing Optimization of the profit by adjusting operating variables and modifying the process to improve production capacity or quality.

There is recognition that, whilst economic evaluation techniques have served the industry well, there are growing challenges in how to define 'value', particularly related to the long term sustainability of the human race and the planet. Chemical Engineers and economists must respond to this challenge to ensure that chemical process which can improve the quality of life continue to be 'economically' viable.

1. Introduction

The Chemical Process Industries have played an important part in the economic growth of nations. Humankind has been able to use its knowledge of the natural sciences to invent large scale manufacture of chemical products to enhance the quality of everyday life. The chemical processes transform raw materials into more useful and therefore, more valuable materials that provide benefits to the end users. Fertilizer manufacturer, for example, enables more productive use of land to provide higher yields of important crops. This ability to take a raw material and add value through its transformation into something more useful creates economic wealth and ultimately improves the living standards of people.

In order to sustain the manufacture of useful products the processes must be economically profitable. In other words the costs of manufacture must be less than the income generated through product sales. Therefore, it is vitally important to assess the economic benefits of investments in new processes to ensure that the venture is economically viable and sustainable. This is not a one-off exercise at the start of a project but an ongoing process throughout the entire lifetime of the chemical plant as it is adapted and modified to improve the manufacturing process, change product characteristics, replace obsolete equipment, respond to changes in environmental and safety legislation and so forth.

Process economics is an important element of the Chemical Engineering discipline and is concerned with the Optimization of profit which is determined by the process engineering design and ultimately operation. The Optimization, therefore, requires an ability to determine the influence of processing techniques and sequencing, and equipment design and operating parameters on the economic performance.

Despite the Chemical Process Industries covering a diverse range of products the principles in determining the value of these processes are the same and are drawn from economics. This paper will discuss the main methods employed to evaluate projects and optimize operations in the Chemical Process Industries.

1.1. The Economic Nature of Chemical Processes

Chemical processes fundamentally transform raw materials into more useful products that are consequently of higher value. In its simplest form a chemical process consists of a series of material and heat flows which can be represented by a simple model as shown in Figure 1:

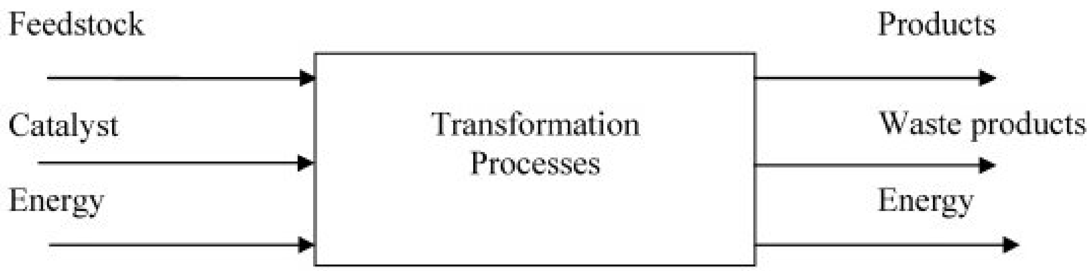

Figure 1. Chemical Process Schematic

Each of these material or energy flows has an economic value either as a cost or a source of income. For instance, energy consumed in a process will have a cost which reflects its generation and transmission but it may also be possible that a process generates a source of energy that can be utilised and sold to a third party thereby generating income.

At the heart of most chemical processes is a chemical reaction. The stoichiometry of the chosen transformation process will set the material and heat flows for the process and ultimately the economics for that process.

This can be expressed in a general sense as:

$$\text{Feed A} + \text{Feed B} + \text{Contaminants} \underset{\text{Catalyst}}{\overset{\text{Heat of reaction}}{\rightleftarrows}} \text{Product C} + \text{Waste Product D}$$

The stoichiometry and thermodynamics of a chemical reaction determines the degree to which the feed materials are converted to products as well as the overall heat requirements. The effluent from the reactor will contain unconverted feed, products and contaminants. Unconverted feed material is separated and recycled or re-used to improve the product yield. Products will have to be separated from the waste products and waste products will need to be treated such that they can be re-used, recycled or disposed of in an environmentally sound manner.

All of this processing requires additional unit operations which have energy requirements in the form of electricity, steam, cooling water, refrigeration etc. These demands will have to be met by generating on site or importing from third parties. Therefore, from the choice of reaction route the process flowsheet containing all the necessary unit operations can be defined with associated costs and revenue streams. The influence that each of the material and energy streams have on the economics are considered in turn below.

1.1.1. Feedstock

The cost associated with feedstock is determined by both its quantity and quality. The quantity required is a function of the reaction yield to produce the desired amount of product. The quality of the feedstock defined by its purity of reactant is an important factor in reducing the quantity of unwanted by-products and/or waste products from the reaction. The presence of impurities can also reduce catalyst activity and increase corrosion leading to the introduction of further processing steps, higher operating costs to replace catalysts and the use of more expensive corrosion resistant materials for equipment fabrication.

1.1.2. Catalyst

Catalyst selection is usually made on the basis of product yield and selectivity. Optimization of the catalyst can reduce investment and operating costs. For instance, a reduction in residence time will therefore reduce the equipment size for a given capacity and allowing the reaction to occur at lower operating temperatures and pressures leads to thinner walled vessels potentially made of cheaper materials.

1.1.3. Energy

A major cost for most chemical processes is energy. Energy streams are required in a variety of forms both as sources of heat and also as heat sinks e.g. steam for heating, electricity for pump and compressor motors, water for cooling. It is always desirable to use energy efficiently. The choice of reaction route is often one of the most important factors in determining the overall energy requirements of a process and once set can be difficult to subsequently optimize throughout the life cycle of the process. There are also opportunities to produce useful forms of energy that can be optimized. For example, the heat generated by exothermic reactions can be used to generate steam for use in the process thereby minimizing heat import requirements with the balance exported to be used by a third party thus attracting a value.

1.1.4. Products

The major source of revenue that determines the economic performance is the product streams. Like the feedstock, the two important parameters are the quantity and quality. The quantity is determined by the reaction route, quality of the feedstock and catalyst selection. This parameter often sets the primary processing objective of a chemical process. The value of a product is set by its quality measured in terms of purity of the chemical species or desired function. Quality influences not only the value of a product but it will determine the investment and operating costs by dictating the downstream (of reactor) separation steps required to meet a quality objective.

1.1.5. Waste Products

Waste products are those materials that have no utility and therefore no value. Most waste products attract a disposal cost and should therefore be minimized. Waste products come in a variety of forms – products of side reactions involving feedstock impurities, combustion products, solvents used in separation processes e.g. water, purges, fugitive emissions etc. The waste streams are hence defined in large part by the choice of process route. The costs associated with waste streams are incurred by the requirement to treat waste streams to make them suitable for disposal into the environment e.g. water effluent treatment and disposal tariffs or taxes imposed by national or local government. Current economic systems do not always allow a cost to be assigned to a waste stream e.g. combustion products. However, engineers have a responsibility to take into account the deleterious effects on human health or the environment and factor this into the decision making process.

1.1.6. Interactions

The setting of the overall heat and material balance is therefore a critical step in any project to develop a process for manufacturing a particular chemical. The above discussion illustrates that the Optimization of a process from an economic perspective is complex and requires trade-offs to be made between competing factors. For example, the selection of reaction route may require the choice between a process that requires more expensive feedstock but is less energy intensive and a process, that although the feedstock is inexpensive, could require a high pressure and temperature for the reaction and involve more downstream processing steps to separate the final products.

There are usually a large number of technically feasible options available to meet a particular process objective for a new plant. Methods to evaluate the economics in a standardized format to facilitate decision-making and Optimization of designs have been developed. Employing these methods allows organizations to decide on which projects to pursue and also how to optimize the design in order to maximize the benefits. The next section discusses these methods in more detail.

2. Economic Evaluation of Chemical Process Projects

The preceding section considered the influence of the process engineering design on the economics of a process plant. However, the net profit from the operation of a process plant equals the total income minus all the costs associated with its operation including the administrative functions. For new process plants or modifications to existing process plants the cash flow across the entire lifecycle of the project must be considered to determine the economic performance. A typical project lifecycle cash flow is represented below in Figure 2. The numerical values are for illustration purposes only.

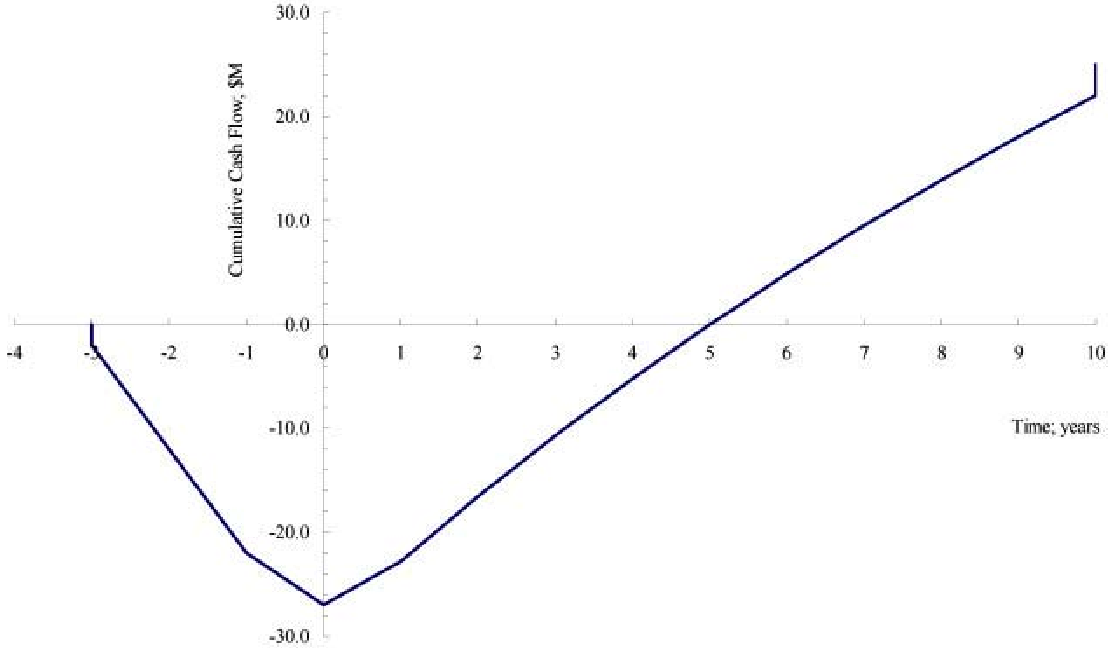

Figure 2. Project Cash Flow Curve

Year 0 represents the point at which the project to construct the process plant has finished and the plant is put into operation. For the three years prior to the plant start-up capital investment is required to design, build and install the process plant. During this phase of the project the cash flow is negative. The total capital investment at time zero includes the land cost, fixed capital investment and working capital. From Year 0 onwards the income on an annual basis (after tax) becomes positive and the cumulative cash flow increases with time. At the end of Year 4 (beginning of Year 5), the cash flow becomes positive indicating that the capital investment is completely repaid. This time period is known as the payback time. At the end of the project life (Year 10) when the operation ceases and the plant is shutdown, the working capital and land value are recovered. The working capital recovery comes from sales of feedstock, stored product and equipment. At the end of the project the overall net cash flow is positive meaning that wealth has been created by the project which can then be distributed to shareholders or used for future investments.

Any project for a new process or modification to an existing process must be able to estimate and then optimize the cumulative cash flow curve. It is important to ensure that there is sufficient confidence in the project outcome prior to investing large sums of money. Figure 2 demonstrates that the actual income from a project could take several years to materialize; therefore, these cash flows must be estimated ahead of time prior to any major expenditure. As the project progresses they must be refined and re-evaluated to ensure that the capital investment remains worthwhile.

Because projects constitute cash flows over relatively long timescales it is important factor that the time value of money is taken into consideration. The value of money invested in a bank must be conserved over time, which is achieved through the payment of compound interest. Money not invested in a bank will therefore decrease in value with time. This means that projected future cash flows must be discounted at an appropriate rate of compound interest, i, for comparison purposes to the present day value of money. The present value, P_V, of a future cash flow, C in year n is thus:

$$P_V = C\ (1+i)^{-n} \qquad (1)$$

The cumulative cash flow curve can then be constructed by summing the present values of all income and expenditure for each year. The cumulative value over the entire lifecycle of the project is called the Net Present Value (NPV) and represents the net wealth in today's money that has been created (or destroyed). In order for a project to be economically viable the NPV must be positive and this is often one of the measurements used for comparing capital projects as discussed in Section 3 below.

2.1. Costs of Chemical Process Projects

The costs that must be taken into account during the economic evaluation of a project to build or modify a process plant can be broken down into two main categories – capital investment and operating costs. The capital investment is the initial outlay to fund the purchase and installation of the process plant. The operating costs are those ongoing charges required to continue the operation.

2.1.1. Capital Investment

The capital investment consists of two elements – fixed capital and working capital.

The fixed capital is the money necessary to purchase and install all the equipment required for the complete operation of the process. It is sub-divided into *direct* and *indirect* costs.

The direct costs include the following items:

- Purchased equipment – all equipment on the process flowsheet, spares, surplus, inflation allowances, freight charges, taxes, import duty, insurance.
- Purchased equipment installation – installation, structural supports, insulation and painting.
- Instrumentation and controls
- Piping – pipes, supports, fittings, valves etc.
- Electrical systems – switchgear, motors, cable, lighting and installation etc.
- Buildings – platforms, stairways, ladders, cranes, lifting equipment, control rooms, maintenance workshops, administrative buildings, laboratories, heating and ventilation, communications etc.
- Site preparation – roads, civil works etc.
- Utility systems – steam, water, power, refrigeration, instrument air, fuel, waste treatment and disposal
- Non-process equipment – office furniture, fire fighting equipment,
- Distribution systems – raw material receipt and storage, product storage, loading stations etc.

- Land – property, surveys and fees.

The indirect costs include the following items:

- Engineering and supervision costs – process design, administrative, discipline engineering design, consultants, travel, supervision, inspection etc.
- Legal fees – national and local regulations, regulatory permits and approvals, contract negotiations etc.
- Construction – construction, operation and maintenance of temporary facilities, offices, roads, construction equipment, material handling, safety and security etc.
- Contractors' fees.
- Contingency.

The working capital for a process plant consists of the funds (cash) required to operate the plant. These funds are replaced on a monthly basis from product revenues but they must be invested up-front to establish operations and are only fully recovered when the production ceases and the project lifecycle is completed. The working capital includes the cost of stored raw materials and supplies, product in stock and semi-finished in the process, cash required to pay monthly operational expenses such as salaries, accounts payable, accounts receivable and taxes payable.

2.1.2. Operating Costs

The operating cost or total product cost is the sum of the manufacturing costs and the general administrative expenses. The manufacturing costs consist of the following items:

- Direct production costs – raw materials, utilities, maintenance, operating supplies, operating labor, direct supervision, laboratory charges, patents and royalties. These are also referred to as variable costs as they depend on the plant operating and to some extent on the production volume. Some items will have an element of fixed cost which is the minimum that would be incurred if the process was shutdown for a period of time.
- Fixed costs – depreciation, local taxes, insurance, rent and interest payments. These costs are independent of production volumes.
- Plant overheads – general plant upkeep, payroll overhead, health, safety and security

The general administrative charges are generally made up of management salaries, legal fees, communications, distribution and marketing costs, and research and development costs.

2.2. Revenue and Profits of Chemical Processes

In order for a process plant to be profitable it must generate products that are of a higher value than the ongoing operating costs. This revenue is generated through product sales. In most competitive chemical markets the product prices are fixed by supply and demand and these can be difficult to forecast. In order to overcome this problem, most organizations will set a standard product price used to test the economics of projects.

This price is usually set by considering the long term demand outlook and the current and future supply capacity. A lot of bulk chemicals are subject to cyclical prices depending on season of the year and global product demand cycles. In order to ensure a project is economically robust the assumed price for economic appraisal usually reflects the perceived financial risks and varies in chemical sectors and across organizations.

It is important when estimating revenues to take into account the expected availability of the plant. Whilst a plant may have a design capacity for a particular product expressed in tonnes per annum, it is unlikely that it will be able to achieve this rate continuously. Planned and unplanned maintenance of equipment will reduce the production capability and there will often be longer periods of no production during which time major maintenance occurs. These factors must all be taken into account when projecting future revenue.

The operating profit (pre-tax) is calculated on an annual basis by subtracting the total operating costs from the total revenues for each year. Before any tax is calculated, the depreciation charges must then be subtracted from the pre-tax profit. Depreciation is an allowance made for the fact that process plant and equipment will wear out over time due to use.

Depreciation is a mechanism whereby revenue is set aside in order to replace the equipment at the end of its useful life. This money can be deposited in a bank account or invested in another venture. This cost is recognized as a legitimate expense by governments under the tax laws and there are therefore strict guidelines in place to account for it. There are two main mechanisms – straight line depreciation and declining balance. Straight line depreciation takes the original purchase value of the equipment and divides this by the expected lifetime in years; therefore, equipment with a 10-year life would be depreciated by 10% per year. Declining balance uses an exponential decay function to reflect the fact that equipment depreciates in value at a higher rate in the first few years of its useful life. The depreciation is thereby recalculated each year on the residual value.

The final post-tax profit is calculated by subtracting the tax from the operating profit less depreciation.

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Biographical Sketch

Colin Deddis is a Chartered Chemical Engineer with almost 18 years experience, predominantly in the oil and gas industry. He began his career with BP in oil refining and gas processing supporting operations and brownfield projects before moving into BP's upstream business where he has held positions supporting offshore production operations and as a lead process engineer on major projects. In the last several years he worked as a lecturer in Chemical Engineering Design at the University of Cambridge before moving back into the oil industry as an engineering consultant prior to rejoining BP in 2007. Colin is currently a Senior Process Engineer working in BP's Exploration and Production Technology Group. In this role he provides internal technical services to major projects and operations and is involved in technology development in the areas of separation and sand management.