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capital and operating cost estimating aspects of environmental control technology - residue hydrodesulphurisation as a case example

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ABSTRACT

Capital and operating cost estimates require a defined data framework to allow comparative scrutiny and meaningful correlation to be made with other estimates for the same and alternative technologies. The various elements of control technology cost estimating are described under the headings of:

- Capital cost
- Capital charge
- Fixed and variable operating costs
- Loss
- Indirect costs/benefits

Special emphasis has been put on capital cost estimating and the concept of capital charge. An accuracy of ± 30% is considered sufficient for capital cost estimates to allow ranking of different control technologies. This means putting emphasis on the identification and inclusion of the main cost items, rather than going into fine detail on equipment, and on clear statements of the assumptions made. A worked example is shown of a particular residue desulphurisation case. This shows that capital charge makes the largest single contribution to annual costs followed by energy and loss.

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1. INTRODUCTION

The development and assessment of alternative environmental control strategies requires reliable information on the costs of available control technology. It is particularly important in the case where alternative technology is available, that the costs are as comparable as possible. Ideally, all such costs should be produced in a standardised form. However, because of the diversity of technology and sources of information, this is not considered to be a realistic aim. A minimum requirement for reliable cost reporting is a clear account of which elements have been included and on what basis. The following Sections identify the essential elements required to produce costs of control technology in such a way that they can be considered reliable in an absolute sense and also can be adjusted for comparability with other estimates.

2. THE ELEMENTS OF COSTING

Costs can be conveniently split into:

- Capital, i.e. money required to acquire and install the hardware necessary.
- Operating, i.e. money required to operate the hardware.
- Indirect, i.e. costs or benefits indirectly associated with the operation of the plant.

For the costs to be meaningful, it is necessary to define three external factors.

- The currency used and its relation to other main currencies at the time the estimate is made.
- The year for which the costs are applicable.
- The location (e.g. country, geographical area) for which the costs are applicable.

3. CAPITAL COSTS

At the heart of a reliable capital cost estimate is the definition of the project. The more detailed the definition the more accurate the estimate. Since definition requires considerable effort and can be time-consuming, it is important to establish what accuracy of estimate is required. At one end of the scale is a scouting-type estimate which can be used for general orientation and for the elimination of clearly uneconomic options. Such estimates require minimum time and effort and typically have an accuracy of ± 30%. At the other end of the scale is a high definition type estimate which requires detailed descriptions of all important pieces of equipment and therefore requires a large effort. It is used for taking investment decisions and budgeting and has typically an accuracy of ± 10%. For environmental strategy evaluation, a scouting type estimate of ± 30% accuracy will in general be sufficient. Although this is the minimum definition case, this does not mean that the definition of a case should be neglected or oversimplified.

A simplified plot plan should be made, identifying the plant capacity, nature of feedstock, the main equipment and all important auxillary equipment. Appendix 1 shows such a plan for a residue hydrodesulphurisation unit (RDS). It should be noted that in addition to the RDS plant itself, hardware is included for hydrogen production, sulphur recovery and the fractionation of products.

It should also be noted that hardware in general require certain supply facilities like steam, electricity and catalyst/chemicals and disposal facilities such as for waste water recovery and spent catalyst, as well as tankage for inlet and outlet streams. All of these are classified as off-plot facilities and the scope and cost thereof is highly dependant upon the particular location. Because of the diversity of possible locations it is not practicable to identify off-plot equipment for a generalised case and it is general practice for an estimate of ± 30% accuracy to express off-plot capital costs as a percentage of on-plot cost. CONCAWE practice is to apply 35%. It should be emphasised that locations will exist where this percentage is too high or too low.

To assist in the task of establishing reliable on-plot costs, in addition to a plot plan, a check-list of required equipment should be made for the specific type of control process, e.g. residue desulphurisation (RDS), flue gas desulphurisation (FGD), gas oil hydrodesulphurisation (GOHDS), by technologists expert in the particular field. This will ensure that no important item is left out of the estimate.

A significant item which must be included in the capital cost is the manpower cost associated with the design and engineering of the technology, equipment and materials procurement and construction onsite e.g. in an oil refinery. In the case of an off-the-shelf piece of equipment, this cost will normally be included in the price but for complex refinery technology each case must be assessed separately. In addition, to cover the evaluation and definition of the project in the phase leading up to the start of the project and the owners supervision and control activities, so-called owners manhours costs should be added, normally as a percentage of total cost. Lump sum license fees should also be included. Throughput linked royalties should be included under operating costs.

A further item that can be of significance is the estimation of the actual cost of the equipment. A world-wide possibility to purchase will in general lead to a lower cost than if there are purchasing restrictions e.g. favouring a national manufacturing industry. Some indication of the assumed point of purchase should be included with the estimate.

For the case in which the control equipment is to form an addition to the existing plant, so-called retrofitting as could be the case for FGD plant, it may be necessary to consider the cost of items such as extensive flue gas ducting or even the relocation of some existing equipment. It is extremely difficult to give general capital estimates for retrofit situations.

Since a cost estimate is based on a number of assumptions, some provision has to be made for unforeseen costs. A proportion of the inside plot costs is therefore added as a contingency.

Finally, the installation of new equipment in an operating refinery is not normally possible without shutting-down part of the refinery for a period. Ideally this should coincide with a shut-down for normal overhaul. This is, however, often not possible and the loss of capacity will result in loss of revenue which should be included under the heading "other once-off costs".

4. OPERATING COSTS

These costs can again be split into:

- Fixed operating costs
- Variable operating costs
- Capital charge

4.1 FIXED OPERATING COSTS

These are the costs incurred to operate the plant irrespective of plant throughput.

They include:
- Operating manpower
- Maintenance (material and manpower)
- Overhead (cost of services which are shared with other plant, e.g. managerial, insurance, property)

Maintenance is often expressed as a percentage of capital, normally 1-3% depending upon the type of plant. Overhead is also expressed as a percentage, for example 50% manpower plus maintenance.

4.2 VARIABLE OPERATING COSTS

These are the operating costs that are dependant upon throughput. They include:

- Energy, both direct fuel and indirect such as electricity and steam
- Cooling water
- Catalyst and chemicals
- Royalties (These can be included here if they are throughput dependant or under capital if they are in terms of a lump sum licence fee).

4.2.1 Loss

Industrial processes in general result in some loss of feedstock/ products due to evaporation, the generation of waste and liquid effluents. In the case of oil, the hydrocarbons lost have a value and their loss must be seen as a cost to the process. A special case of loss is the production of hydrogen from hydrocarbon feedstocks from which there is a significant co-production of CO_2 having no value and which therefore represents a loss. NH_3 and H_2S are other components produced which also represent a loss of intake and thus value.

4.3 CAPITAL CHARGE

This item can be the cause of considerable misunderstanding and is therefore treated in some depth. The capital cost for a particular piece of equipment is the money that must be laid down largely before the plant becomes operational. In general, there is always a shortage of money for investment in new projects. It is therefore necessary to assess the economic consequences of taking away money from other possible projects or from money that has been invested. If it is assumed that other projects or investments will earn a certain acceptable return, then any new project must earn at least this same return otherwise it will be an unacceptable investment. The minimum return may also be expressed simply as the cost of having to borrow money, or in extreme cases, to the interest that could be earned by leaving the money in the bank.

Accepting that investors will always require a minimum return on the money they invest, which will represent the alternative use value, a capital charge is defined as: A means of expressing a once-off expenditure in the form of a cost per unit of time or quantity over the lifetime of the asset and represents the margin that must be earned to give a preset return on capital. It is based on the discounted cash flow method. It is normally expressed as a percentage of the capital expenditure. In order to establish a capital charge it is necessary to define the following most important elements:

a) Required minimum return on capital (for the reasons explained above).

b) Effective lifetime of the asset. Clearly if the asset is capable of recovering a margin over a long period, the capital charge can be lower than if the asset has only a short margin recovery capability. Two important aspects can affect the lifetime, viz. physical/technical obsolescence and economic non-viability. The first can be reasonably well assessed. The second is less predictable since it can result from events outside the control of the decision maker. If in his opinion there is a significant risk associated with the continuing earning of a margin e.g. because the product involved may be priced out of the market or the technology can become uncompetitive with newer technology, then a shorter lifetime or a higher return, both leading to a higher capital charge, may be decided upon to cover the risk.

c) Taxation/fiscal depreciation. If the investor is in a tax-paying position (the normal situation), the tax-rate and the allowed fiscal depreciation must be taken into account to give a required return after tax. Both will increase the capital charge.

d) Inflation. If significant inflation is expected over the life of the asset, allowance should be made in calculating capital charge. The higher the inflation rate the greater the capital charge required.

The above list of factors affecting capital charge is not exhaustive but includes the most important. Other factors that may need consideration are, phasing of capital expenditure, inclusion of working capital, and plant loading especially in the initial phase of the operation. Appendix 2 shows an example of a simplified capital charge calculation.

Clearly each project under consideration will have its own values for the factors. A calculation has been made of capital charges resulting from rates of return after tax in the range of 10-15%, asset lifetime range of 10-20 years, tax rate 0% and 50%, inflation less than 5% year. The results are shown in the following table.

The Relationship between Capital Charge, Required Rate of Return and Asset Lifetime

Required rate of return % on capital/year (after tax)	10		12		15	
Asset life (years)	Capital charge (% on capital) Tax Rate (%)					
	0	50	0	50	0	50
10	17	24	19	27.5	21	33
15	15	21	17	24.5	19	30
20	12.5	17.5	14	21	17	26.5
Average	14.8	20.8	16.7	24.3	19	29.8

Inflation: Less than 5%/year

This shows the considerable range of capital charge that can be obtained. The overall average at zero tax is 17% and at 50% tax is 25%. As mentioned already, tax is usually being paid at rates of about 50%. CONCAWE has been using a capital charge of 25% since the early '70s.

It should be appreciated that typical values for the factors affecting capital charge will differ from sector to sector. For example the public utility sector can normally count on long lifetimes for its equipment and its income is less liable to competitive pressures than that of free-enterprises. Both effects lead to being able to accept lower capital charges than those required for free-enterprises.

These aspects are important when comparing, for instance, the cost of desulphurisation in oil refineries with that in power stations.

5. INDIRECT COSTS/BENEFITS

When assessing the costs of a control measure, consideration must be given to whether there are any indirect effects that can have an influence on the costs. These effects may be cost increasing or decreasing. These are best illustrated by examples.

- Residue hydrodesulphurisation occurs at high pressure and temperature in the presence of hydrogen which in addition to sulphur removal, results in a conversion effect to lighter hydrocarbons. These have a higher value than the residual feedstock and this higher value must be assessed resulting in a cost reducing effect.

- If the costs of producing elemental sulphur are included in the HDS costs, then the value of such sulphur should be taken into account. This will give a (small) cost reducing effect.

- Flue gas desulphurisation produces significant amounts of by-product or waste solids depending upon the process being considered. In some cases, disposal is easily possible so that no costs and even perhaps a small benefit is obtained. In other cases, disposal can be a serious problem involving significant costs. This will give an FGD cost increase effect.

6. CONCLUDING COMMENTS

The foregoing Sections have described in more or less detail what is required to arrive at reliable and comparable costs of control technology. Appendix 3 summarises the elements in the form of a check list. Appendix 4 shows as an example, a worked out case for the costs of a residue desulphurisation plant. The details given should be sufficient to allow comparison with other estimates of RDS costs and to identify possible significant discrepancies.

The costs given in this example should not be considered representative of RDS costs in general. CONCAWE Report No. 4/86 gives a more complete picture covering four different feedstocks and two capacity levels. The total annual costs can be expressed in several ways i.e. per ton feedstock, per ton 1% sulphur fuel oil, per ton sulphur removed. The following table summarises the results from Report No. 4/86 on a cost/ton S removed basis.

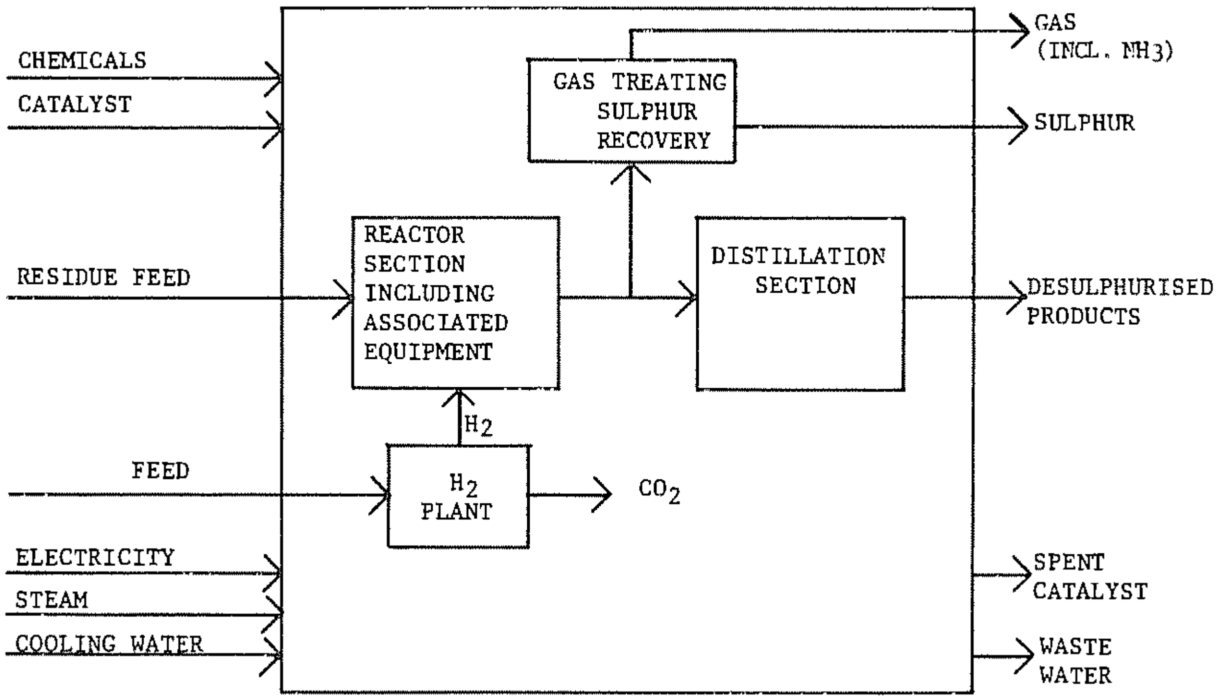
Feedstock (4000 t/cd intake)	Kuwait vacuum residue	Arabian light vacuum residue	Arabian heavy vacuum residue
$/t S removed	1200 - 1850	1250 - 2100	900 - 1750

It is clear from Appendix 4 that capital charge is the largest single item, which is normally the case for refinery based control technology. For RDS, energy and loss are important cost items and indirect benefits can also be significant.

7. REFERENCES

CONCAWE (1986) Residue hydrodesulphurisation, investment and operating costs. Report No. 4/86. The Hague: CONCAWE

APPENDIX 1 - RESIDUE DESULPHURISATION SIMPLIFIED INSIDE PLOT DIAGRAM



APPENDIX 2 - AN EXAMPLE OF A SIMPLE CAPITAL CHARGE CALCULATION

Capital cost	$C
Capex phasing in year 1	100%
Net annual income before tax in each year of project	$I
Tax rate applicable	NIL
Project lifetime	10 years
Minimum return required	10%/year
Inflation	less than 5%

The above allows a discounted cash flow to be built up which separates the capital outlay and the cash income.

YEAR	CAPITAL COST	DISCOUNTED CAPITAL	NET INCOME BEFORE TAX	LESS TAX	DISCOUNTED CASH INCOME
1	C(b)	0.953 C	-	-	-
2	-	-	I	-	0.867 I
3	-	-	I	-	0.788 I
4-11(a)	-	-	8 I	-	4.204 I
TOTAL	C	0.953 C	10 I	-	5.859 I

(a) It is normal that a 10 year lifetime refers to 10 years from start-up which in this case is from year 2 to 11.

(b) For a large item, capital spending will be spread over more years.

Referring back to the definition of capital charge this requires the discounted capital outlay to equal the discounted cash income, thus:

$$0.953\ C = 5.859\ I$$

or

$$I = 0.163\ C$$

The capital charge expressed as a percentage is thus 16.3. In other words, an annual capital charge of 0.163 C has to be applied over the 10 years lifetime of the project in order to obtain a 10% earning power from the capital employed.

APPENDIX 3 - CHECK-LIST FOR ESTIMATING THE COST OF ENVIRONMENTAL CONTROL TECHNOLOGY

The following summarises the various elements necessary to enable a reliable cost estimate to be made.

General

Location
Year for which costs are applicable
Relationship of currency used with other main currencies
Capacity of plant
Feedstock
Removal efficiency
Greenfield or existing site

Capital cost

Main plant check list/plot diagram
Design/engineering/procurement/construction cost
Contingency allowance
Off-plot costs
License fees
Purchase point of equipment
Owners costs
Retrofit

Other once-off costs e.g. from temporary shut-down of existing plant.

Operating costs

Fixed

- Operating manpower
- Maintenance (manpower + materials)
- Overhead

Variable

- Energy direct fuel + indirect (electricity/steam)
- Cooling water
- Catalyst and chemicals

Royalties (if not included under capital)
Loss of hydrocarbons
Capital charge

Indirect costs/benefits

It should be noted that published cost estimates of control technology will often report the cost for a number of items on the check list as one figure. This is for reasons of confidentiality and/or to protect a commercial position.

APPENDIX 4 - COSTS OF RESIDUE HDS

The data for this example has been taken from CONCAWE Report No. 4/86 "Residue hydrodesulphurisation investment and operating cost". In order to simplify the presentation, one particular case is shown in detail. The result should not be taken as a general indicator for RDS costs.

Basic Definitions

Location	Rotterdam
Year for which estimate applicable	mid 1985
Currency	1 \$ = 2.85 DEM = 3.20 NLG = 239 Yen = 0.73 £
Equipment Procurement	World-wide

Process Definitions

Feedstock	Arabian heavy vacuum residue
Capacity	Feedstock intake 4000 t/cd
Desulphurisation rate	Lowest economically possible (in practice about 85%)

Capital	$\$ \times 10^6$
Reactor section	79
Facilities associated with reactor section	44
Fractionation facilities	15
Sulphur recovery	5
Hydrogen unit	39
Process tie-ins	8
Total inside plot	190 (a)
Outside plot (35% of inside plot)	67
Total capital	257

(a) Includes 20% contingencies

Operating	$\$ \times 10^6$/year
Fixed	
Operating manpower (35 men at \$30 000/man-year)	1
Maintenance (1.5% of inside plot capital)	3
Overhead (50% manpower + maintenance)	2
	6

	$ x 10^6/year	
Variable		
Energy ($209/ton 1% sulphur residue)	23	
Catalysts/chemicals/royalties/miscellaneous	10	
Loss (hydrocarbons, ammonia, hydrogen sulphide) (costed at $189/ton intake)	23	
	56	
Capital charge (25% of capital cost)	64	
Total operating cost	126	
Indirect costs/benefits		
Upgrading benefit	15-38	(a)
Sulphur benefit	3	(b)
	18-41	
Net annual cost	85-108	

(a) Based on: Gasoline and lighter 99 000 t/yr at $113/t above feedstock value

Middle distillate gain 580 000 t/yr at $10-50/t above fuel oil value

(b) Based on: Sulphur recovered 61 000 t/yr at $50/t

Expressing these costs as $/t sulphur removed gives $1328-1688/t S.

CONCAWE Report No. 4/86 should be consulted for a complete overview of RDS costs.