# DEVELOPMENT OF MECHANISM FOR PROJECT COST ESTIMATION

**Thesis**

***Submitted by***

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# DECLARATION BY THE SCHOLAR

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# BONAFIDE CERTIFICATE

This is to certify that the thesis entitled "**DEVELOPMENT OF MECHANISM FOR PROJECT COST ESTIMATION**" submitted by **Ms. PRATHIBHA B IYER (R670215023),** to the University of Petroleum and Energy Studies, for the award of **MASTER OF TECHNOLOGY** degree under Chemical Engineering with specialization in Process Design is a bonafide record of project work carried out by her under our supervision. The results embodied in this project review report are based on literature and the research in HPCL Green R&D Centre. This data is based on proprietary technology of HPCL, and hence only HPCL reserves all the rights to patent, publish and present the data.

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# ABSTRACT

Prior to development of a process, at several phases of its development and before giving an attempt to design the process and plant, the process representative must undertake economic evaluations. When used with appropriate values for the adjustable designs and production (construction) parameters, Aspen Process Economic Analyzer (Aspen PEA) and Aspen Capital Cost Estimator (Aspen CCE) software tools provides a highly detailed and accurate cost estimate of the overall project. The process unit to be modeled using Aspen HYSYS software for mass and energy balance calculations includes all major process steps for selective end objective of the process. This process model was coupled with economic evaluation and capital cost scaling in Aspen Process Economic Analyzer and Aspen Capital Cost Estimator to evaluate the project proposal. The necessary initial parameters such as Project Name, Scenario Name, Units of Measure, Wage Rate, Cost Index, Design Criteria, Investment Parameters and other mandatory specification for achieving the estimated cost needs to be indicated. When the sizing specifications of each of the process equipment were specified, the equipment cost and investment analysis on request would be generated through Aspen PEA. In order to generate and report the capital cost estimation of this project, from Aspen PEA it was fed to Aspen CCE, through which the project capital cost estimation was carried out. The results generated through these tools, were evaluated and validated with the existing estimation of the project evaluated. Finally, the results were also compared with quotes obtained by a standard vendor. These analyses were carried out for a Pressure Swing Adsorption Hydrogen (PSA) Unit and for a Propylene Dryer Unit (PDU), for validation of the methodology demonstrated in this thesis and the results were compared with the existing estimation. This methodology promises for firm and immediate evaluation of any proposal and ensures that a preliminary estimation of the project is carried out.

# Table of Contents

# List of Tables

# List of Figures

# NOMENCLATURE

| | |
|---|---|
| PEA | Process Economic Analyzer |
| CCE | Capital Cost Estimator |
| PSU | Public Sector Undertaking |
| HP-GRDC | Hindustan Petroleum Group Research & Development Centre |
| PSA | Pressure Swing Adsorption |
| PRU | Propylene Recovery Unit |
| $C$ | Concentration |
| $q$ | Amount of adsorption |
| $q_0$ | Adsorption capacity of the adsorbent |
| K | Adsorption equilibrium constant |
| $p$ | Partial pressure in the gas phase |
| $k_a$ | Adsorption rate |
| $k_d$ | Desorption rate |
| $k$ | Boltzmann constant |
| $\varepsilon_b$ | Bed volume void age |
| $D_L$ | Axial dispersion coefficient |
| c | Cross sectional average concentration |
| $u$ | Fluid velocity |
| $q_i$ | Cross sectional average solid loading |
| $N_c$ | Number of - components in the feed |
| L | Length of the adsorption bed |
| z | Spatial co-ordinate |
| CPP | Captive Power Plant |
| LPG | Liquefied Petroleum Gas |
| FCCU | Fluid Catalytic Cracking Unit |
| CEPCI | Chemical Engineering Plant Cost Index |
| $C$ | Purchased cost |
| $I$ | Cost Index |
| $C_{TM}$ | Capital cost of plant |
| FCI | Fixed Capital Cost |
| AACE | Association of the Advancement of Cost Engineering |
| $C_e$ | Purchased equipment |

# CHAPTER 1
# INTRODUCTION

As a role of their task to spot and expand practical and doable processes, process engineers requires performing both orders of significant cost approximation as well as evaluating and assessing cost estimates contained in the proposal. There are numerous tools available to contribute in the working and assessment of cost estimates for chemical process equipment. Aspen Process Economic Analyzer (PEA) and Aspen Capital Cost Estimator (CCE) are one among those. Aspen PEA and Aspen CCE is industrially recognized software tool for generating cost estimates and makes the most of piping, instrumentation, civil, electrical, steel, insulation, self-contained equipments and design algorithms for the purpose of models including preliminary equipment which is property incorporated as well as evaluated for numerous safety and operability concerns. During the application of accurate values for the variable design and construction factors, Aspen PEA and Aspen CCE offer a highly descriptive and precise cost estimate.

## 1.1 BACKGROUND

Hindustan Petroleum Corporation Limited is a vast Public Sector Undertaking (PSU) and is the second largest integrated oil company in India. They have two refineries, one in Vishakhapatnam (East coast) holding a refining volume of 8.3 MMTPA and the other is located at Mumbai (West coast) comprising a refining volume of 7.5 MMTPA. Also, HPCL is about to expand the refining capacity of its Vishakhapatnam refinery up to 15 MMTPA and Mumbai refinery to 9.5 MMTPA.

HPCL R&D is focusing on developing process technologies such as Pressure Swing Adsorption (PSA), HP Hi Gas for deploying in the refining industry. These have been successfully demonstrated by setting up commercial scale plants in HPCL refineries. Other Indian refineries have extended their interest towards HPCL R&D in making these technologies expand commercially. This requires HP-GRDC team to participate in tenders to supply technology in competition with other vendors in the domain.

In view of this, development of a standard Process Design Package, Cost mechanism and documentation for participation in tenders is on priority. Usually, the capital cost estimates for chemical process plants find its basis from the estimate of the purchase cost of the major equipment items necessary for the process. The precision of this type of estimate would rely on which stage the design has reached at the phase the estimate is made, and on the dependability of the data effective on the equipment costs. In view of this, the current running project was taken into account for the cost estimation. The major improvement of adsorption processes on a bigger industrial scale handle chiefly with solid gas and solid liquid interfaces, but in many other laboratory separation procedures, all types of interfaces would be implied. Fluid is a common term used to represent gas or liquid in association with the solid boundary surface. Pressure Swing Adsorption (PSA) is a well-developed gas separation method under air separation section, hydrogen purification and gas drying. Hydrogen is manufactured by eliminating further components or recovering it through gaseous mixtures generated in several chemical processes. Two methods for hydrogen production are Steam reforming and Continuous catalytic reforming. The most common method with the highest efficiency of current commercially available production methods of about 65-75% is steam reforming. Steam reforming of natural gas proposes an economical, efficient, and extensively used method for hydrogen production, and offers near- and mid-term energy security and environmental benefits. Hydrogen produced from steam reforming method includes minute quantities of CO, $CO_2$ and HS as impurities and requires further purification. Recent steam reformer plants utilize a Pressure Swing Adsorption (PSA) unit that has efficiency of 99.99% to purify product hydrogen. The development of this cost mechanism of PSA is on high priority by the organization.

For the some of the propylene production through PRU licenses an additional dryer system must be installed prior to condensation. The removal of dissolved water from liquids is accomplished by passage of the wet liquid through a freshly reactivated packed column of granular desiccant material like silica gel, activated alumina or molecular sieves. Continuous operation is accomplished by the use of dual adsorbers, with one tower on the process stream while the other is being reactivated. A case study of this Propylene Drying Unit (PDU) was also carried out and compared with the existing unit's cost estimation.

## 1.2 FUNDAMENTAL BACKGROUND OF ADSORPTION:

Adsorption is a process that takes an effort to impose selected gas molecules in a mixture entrapped nearby to a solid surface. When a gas molecule is close to a solid surface, the molecules in the solids tend to apply a desirable force over the gas molecule that will decrease its potential energy. The species being adsorbed is known as the adsorbate, while it resides on the solid, and the solid is called the adsorbent. Physical adsorption is one that takes place when the force in the contact between the adsorbing molecule and the surface are fragile and also the adsorbate and adsorbent are kept distinct, while Chemical adsorption or Chemisorptions occurs when the contact forces are strong enough for relocation or sharing of electrons between the adsorbate and the adsorbent.

A few common equations are prevalent for sizing conventional adsorbers and PSA units. They can handle any form of concentration, C, for the fluid phase or convenient units. The simplest equilibrium isotherm reveals loading as proportional to the fluid-phase concentration, and this results in *Henry law* (eq.1.1).

$$q = K\,C \qquad \dots 1.1$$

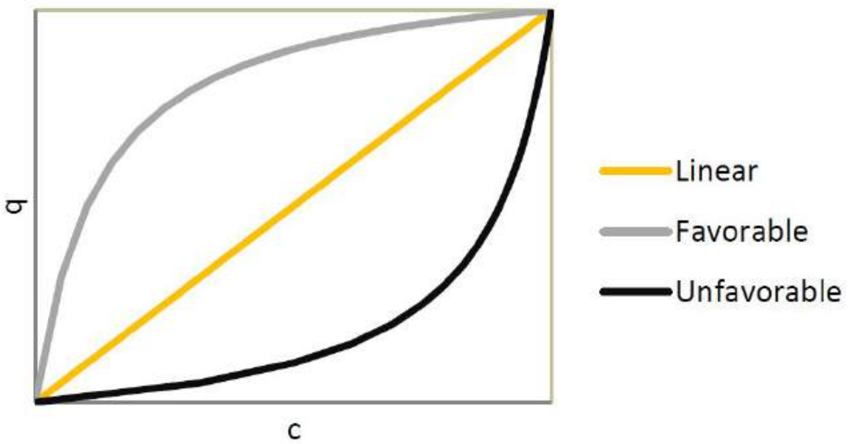



**Fig 1.1: Dimensionless equilibrium isotherm showing the "Linear", "Favorable" and "Unfavorable" plots (Claudia *et al*., 2014).**

Proclaimed by Motoyuki Suzuki (1990), consider a surface coverage or fractional filling of a micropore is $\theta$ *(=q/q₀)* and the partial pressure in the gas phase, *p*, that is replaced by *C (=p/RT)* when the concentration in the fluid phase is used, the adsorption rate is expressed as $k_a p(1-\theta)$ assuming first order kinetics with desorption rate given as $k_d\theta$. The equilibrium relation emerged through the equilibrium of adsorption rate and desorption rate brings about the equilibrium relation as:

$$\theta = \frac{Kp}{(1+Kp)} \qquad \dots 1.2$$

or

$$p = \frac{1}{K}\left(\frac{\theta}{1-\theta}\right) \qquad \dots 1.3$$

The above equation is called *Langmuir* isotherm and $K = k_a/k_d$ is called the adsorption equilibrium constant. When the amount adsorbed, $q$, is way lesser in contrast with the adsorption capacity of the adsorbent, $q_0$, Eq. 2 will be condensed to *Henry* type eq.1.4:

$$\theta = Kp \qquad \text{... 1.4}$$

Additionally, when the concentration is high enough, p>>1/K, then adsorption spots are saturated and

$$\theta = 1 \qquad \text{... 1.5}$$

Considering the interaction between adsorbing molecules, Fowler *et al., (1939)* modified the above equation as eq.1.6

$$p = \frac{1}{K}\left(\frac{\theta}{1+\theta}\right)\exp\left(\frac{2u\theta}{kT}\right) \qquad \text{... 1.6}$$

where, *2u* denotes pair interaction energy, and *k* is the *Boltzmann* constant.

When the adsorbed molecules are free to move on the adsorbent surface (mobile adsorption), the *Langmuir* equation is modified to eq.1.7

$$p = \frac{1}{K}\left(\frac{\theta}{1-\theta}\right)exp\left(\frac{\theta}{1-\theta}\right) \qquad \text{... 1.7}$$

For mobile adsorption with interaction,

$$p = \frac{1}{K}\left(\frac{\theta}{1-\theta}\right)exp\left[\left(\frac{\theta}{1-\theta}\right) + \frac{2u\theta}{kT}\right] \qquad \text{... 1.8}$$

Fig.2 shows deviation of the isotherm relation from *Langmuir*.

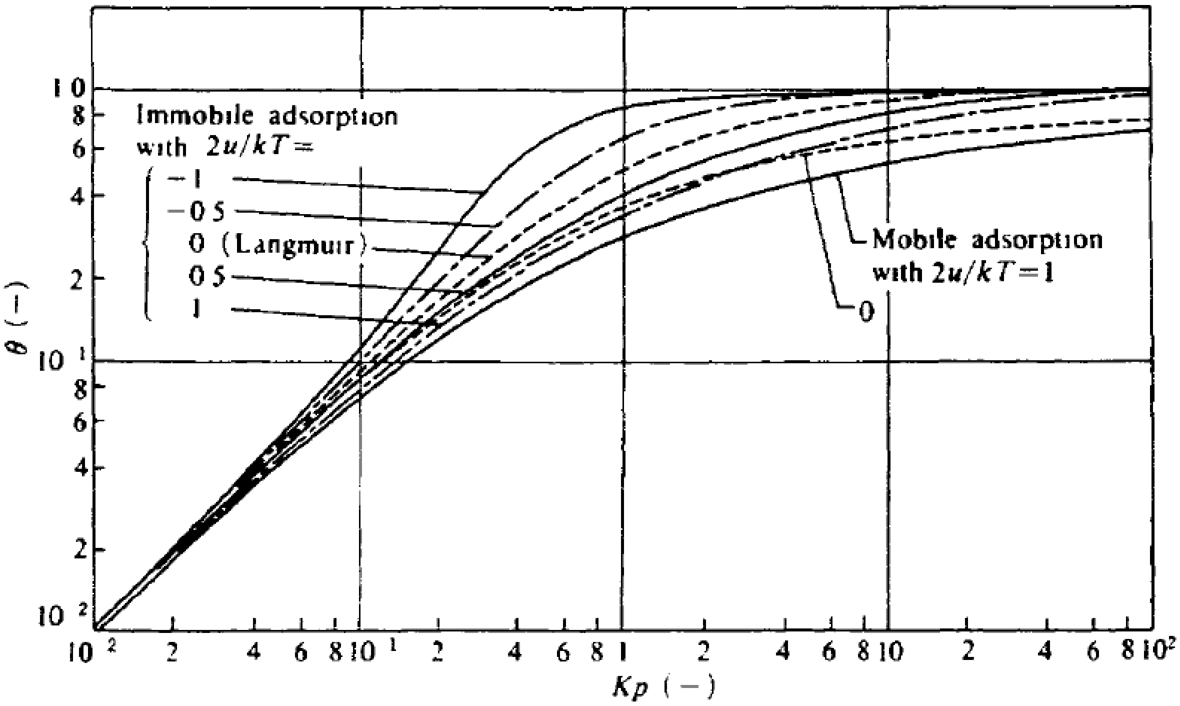



**Fig 1.2: Effect of mobile adsorption and interaction of adsorbed molecules on shape of isotherm (Motoyuki Suzuki., 1990).**

The *Freundlich* isotherm is the result of fitting isotherm data to a linear equation on log-log coordinates. The *Freundlich* type equation is given by eq.1.9

$$q = k_P \, C^{\left(\frac{1}{n_F}\right)} \qquad \text{... 1.9}$$

Examples of correlation of adsorption data taken in aqueous phase are shown in Fig 1.2. The *Freundlich* equation is only applicable below the saturation concentration (solubility or saturation vapor pressure), where condensation or crystallization occurs and adsorption phenomena are no more considerable.

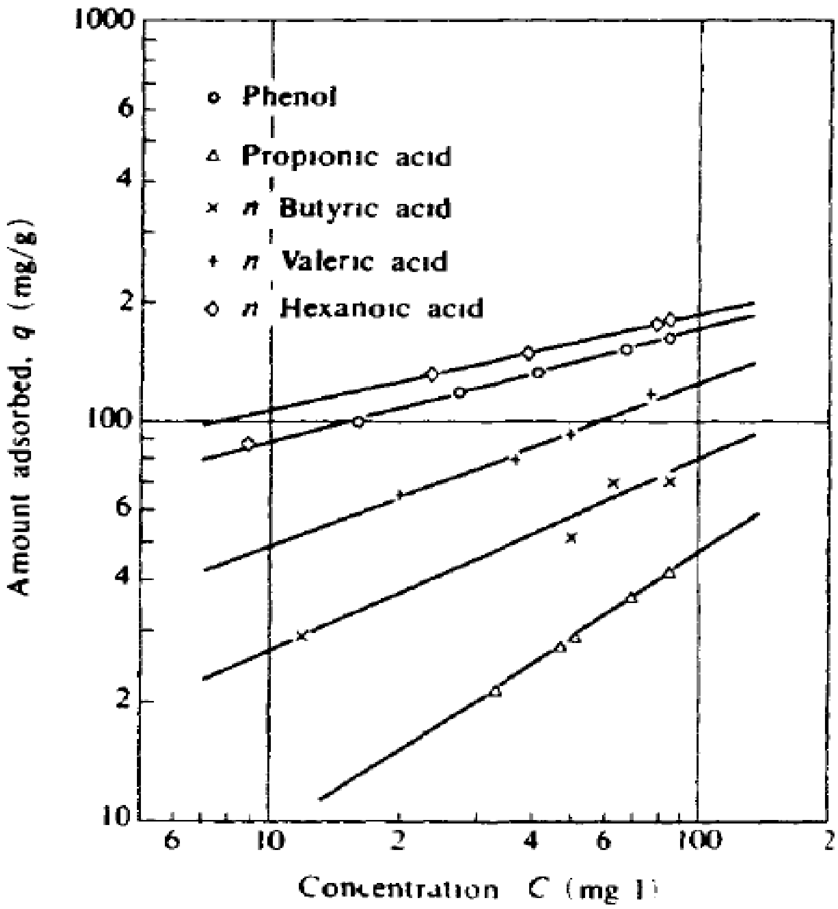



**Fig 1.3: Examples of *Freundlich* plot, aqueous phase adsorption of single component organic acid on activated carbon (Motoyuki Suzuki., 1990).**

Radke *et al.*, (1972) formulated the following eq.1.10, which combines the *Freundlich* equation with the *Henry's* type equation.

$$q = \frac{1}{\left[\frac{1}{K_h p} + \frac{1}{k_F p^{\left(\frac{1}{n_F}\right)}}\right]} \qquad \text{... 1.10}$$

During the immersion of porous particles into pure gas, the pores would load with the gas, and also the amount of adsorbed gas is verified by the reduction in total pressure. The pressure would not change with a liquid, and only complicated experimental procedures have been devised for determining the level of adsorption of pure liquid. If at all the liquid is a homogenous binary mixture, it is conventional to assign one component as the solute A and the other as the solvent B. Then the assumption should be made such that the alteration in concentration of the liquid mixture in connection with a solid adsorbent is entirely caused by the adsorption of the solute. The solvent is taken as non-adsorbed. The adsorption isotherm is likely in the form acquired for pure gases, when the liquid mixture is dilute in the solute,.

Pressure Swing Adsorption (PSA) technology is at the forefront of gas separation technology. PSA are diversely used in industrial applications like air drying, gas purification, solvent recovery among the principles, removal of carbon dioxide, enrichment recovery of rare gases, purification of helium, purification of natural gases, separation of isomers and separation of carbon monoxide. Apparently, the chief applications of PSA are found to be in the production of oxygen from air, dehumidification of gases and purification of hydrogen. The combination of desorption at low pressure and adsorption at high pressure is the notion of PSA.

## 1.3 PRESSURE SWING ADSORPTION (PSA) PROCESS:

The PSA process is based on the principle that adsorbents are capable of adsorbing more impurities at a higher gas-phase compared to the lower partial pressure. The fixed bed adsorber will take up the impurities at high pressure and then discarded as the system pressure “swings” to a decreased level. Eventually, hydrogen is not adsorbed. The capability to totally adsorb impurities permits the production of high purity hydrogen product (>99.9 vol- %). PSA process is a semi-batch-type process that uses multiple adsorbers to provide constant feed, product and off gas (for fuel) flows. An overall pressure-swing series consists of the following five basic steps:

a. Adsorption
b. Co-current de-pressurization
c. Countercurrent de-pressurization
d. Purge at low pressure
e. Repressurization.

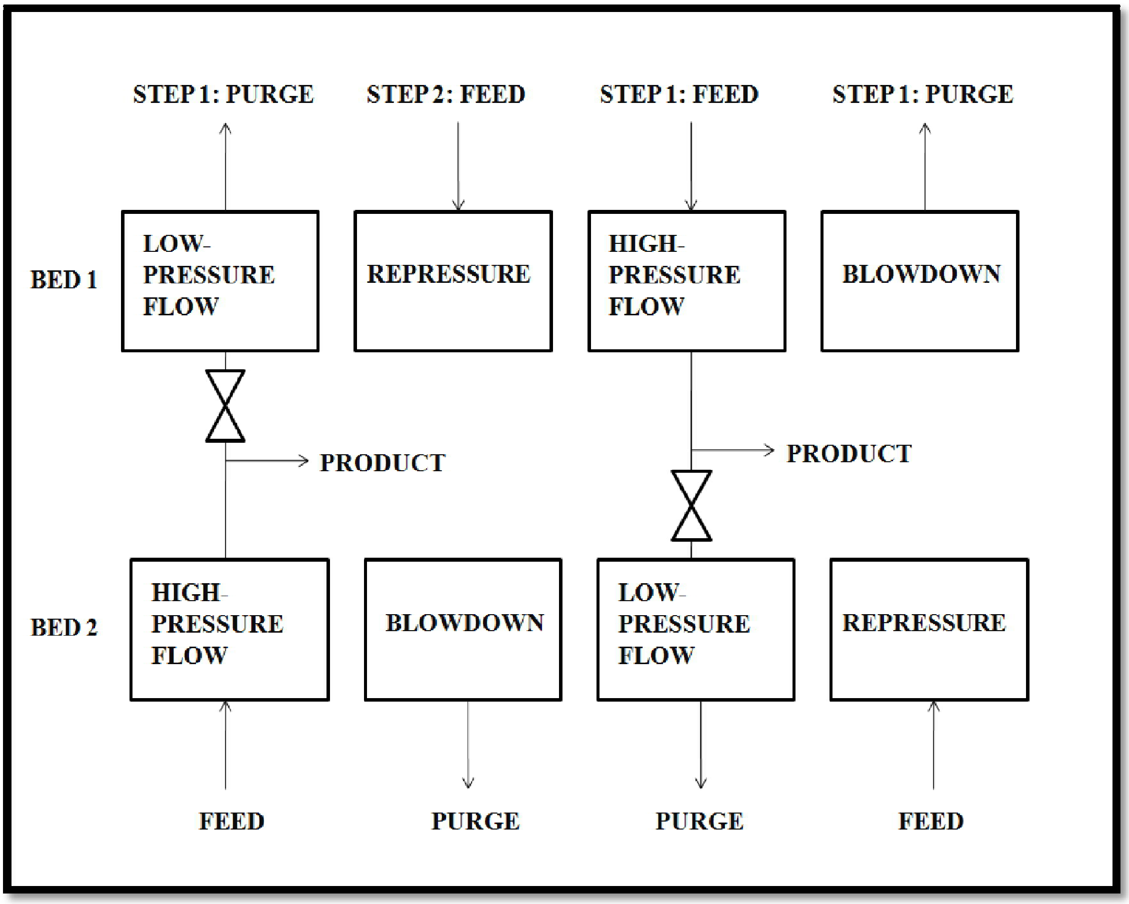



**Fig 1.4: PSA process steps.**

Two parameters determine the choice of a PSA system: the required hydrogen recovery and the unit capacity. Small capacity (less than 5,000 $Nm^3$/hr of feed) PSA units are normally four-bed systems. Large capacity (greater than 50,000 $Nm^3$/hr of feed) PSA units are normally designed for maximum hydrogen recovery, which requires three or more equalizations. Small PSA units should be designed with one or two equalizations at the expense of small recovery loss, since the cost of a PSA unit increases with more pressure equalizations (Stocker J *et al., 1998*).

Mathematical models for describing adsorption and desorption processes are well established and are considered to be in good agreement with experiments. The full set of mathematical equations is typically a large, coupled, non-linear system of equations. Taking into consideration the number of equations employed in all the models related with the PSA process, only the main equations used in the adsorption bed model related with the PSA process is presented in the present section of this work. PSA involves both adsorption and desorption processes, which for a given system typically operate at the same temperature.

The isotherm model should be close to linear to avoid the adsorption or desorption to become too low.

### 1.3.1 Material Balance

The flow pattern in a PSA bed is nothing else than the flow pattern in any fixed-adsorbent bed, which makes the axial dispersive plug flow pattern a suitable model. By assuming this flow pattern model, the material balances for the individual gas components can be described by eq.1.11 (Joakim Henrik Beck).

$$\frac{\partial}{\partial z}(uc_i) + \varepsilon_b \frac{dc_i}{dt} + (1 - \varepsilon_b)\rho_s \frac{dq_i}{dt} = D_L \frac{\partial^2 c_i}{\partial z^2}, \forall z \, \epsilon (0, L], \qquad \text{... 1.11}$$

For i=1,…, $N_c$, where $\varepsilon_b$ is the bed volume void age; $D_L$ is the axial dispersion coefficient; c is the cross sectional average concentration of the component in the fluid phase; $u$ is the fluid velocity; $q_i$ is the cross sectional average solid loading; $N_c$ is the number of adsorbable components in the feed; L is the length of the adsorption bed, and $z$ represents the spatial co-ordinate. The concentration and loading are summarized as cross sectional averages as no radial dependence is assumed. The first and second term on the left hand side in eq.1.11 represents the properties of the gaseous mixture, and the third remaining term accounts for the macropore material balance. The right-hand side, namely the axial dispersion term, represents axial mixing. If the axial dispersion term is omitted, we get the plug flow model. The plug flow approximation is mainly justified when the axial dispersion term is sufficiently small compared to the mass transfer resistance term.

### 1.3.2 Mass Balance

In describing these equations it is assumed that the mass transfer driving force is on a solid coverage basis instead of on a concentration or partial pressure basis (Claudia *et al.*, 2014).

The continuity equation for each species in the fluid phase is given by eq.1.12:

$$\varepsilon_{total} \frac{\partial \rho x_i}{dt} + \frac{\partial \rho u x_i}{\partial z} = \varepsilon_{bed} \frac{\partial}{\partial z}\left(\rho D_{ax} \frac{\partial x_i}{\partial z}\right) - \rho_{bed} MW_i \omega_i (q_{eq.i} - q_i) \qquad \text{... 1.12}$$

The subscript ‘i’ refers to the components in the feed mixture.

For the mass balance the boundary conditions for the inlet and outlet are:

$$inlet: \qquad \frac{F_{in}w_{in}}{A} = \frac{F_{in}x_i}{A} - \varepsilon_{bed}\rho D_{ax}\frac{\partial x_i}{\partial z}$$

$$outlet: \qquad \varepsilon_{bed}\rho D_{ax}\frac{\partial x_i}{\partial z} = 0$$

The mass balance for the adsorbed phase is given by eq.1.13:

$$\frac{\partial q_i}{\partial t} = \omega_i\left(q_{eq.i} - q_i\right) \qquad \ldots 1.13$$

### 1.3.3 Energy Balance

Eq. 1.16 denotes the energy balance for the bed used in the PSA simulations (Claudia *et al.*, 2014).

$$\frac{\partial U_b}{\partial t} = \varepsilon_{bed}D_{ax}\frac{\partial}{\partial z}\left(\rho\frac{\partial h}{\partial x}\right) - \frac{\partial u\rho h}{\partial z} + \frac{\partial}{\partial z}\left(\left(\varepsilon_{bed}\lambda + \frac{(1-\varepsilon_{bed})}{\frac{0.22\varepsilon_{bed}^2}{\lambda} + \frac{2}{3\lambda_{ad}}}\right)\frac{\partial T}{\partial z}\right)$$

$$- k_{T,bw}\frac{4}{d_b}(T - T_w) \qquad \ldots 1.14$$

For this equation, the boundary conditions are:

$$z = 0; \qquad \frac{F_{in}h_{in}}{A} = u\rho h - \varepsilon_{bed}D_{ax}\rho\frac{\partial h}{\partial z} - \left(\epsilon_{bed}\lambda + \frac{(1-\varepsilon_{bed})}{\frac{0.22\varepsilon_{bed}^2}{\lambda} + \frac{2}{3\lambda_{ad}}}\right)\frac{\partial T}{\partial z}$$

$$z = 1; \qquad \frac{\partial T}{\partial z} = 0$$

When calculating the internal energy of the bed, the contributions of both the fluid and the solid phases have to be considered, therefore, eq. 1.15 is used for that purpose.

$$U_b = \varepsilon_T(\rho h - P) + \rho_{bed}\left(\sum_i q_i\, h_{ad,i} + C_{p,ads}(T - T_{ref})\right) \qquad \ldots 1.15$$

The mass specific enthalpy of an adsorbed species is given by:

$$h_{ad,i} = h_i^{\emptyset}(T,P) + \Delta H_{ad,i} + \Delta C_{p,ad,i}\left(T - T_{ref}\right) \qquad \ldots 1.16$$

The heat transfer through the wall of the bed needs to be taken into account so the energy balance model is completed. Eq.1.17 gives the energy balance to the wall.

$$\frac{\left((d_b + 2l_w)^2 - {d_b}^2\right)}{{d_b}^2} \rho_w C_{p,w} \frac{\partial T_w}{\partial t}$$

$$= \frac{\left((d_b + 2l_w)^2 - {d_b}^2\right)}{{d_b}^2} \frac{\partial}{\partial z}\left(\lambda_w \frac{\partial T_w}{\partial z}\right) + k_{T,wa} \frac{4(d_b + 2l_w)}{{d_b}^2} (T_w - T_a) \qquad \ldots 1.17$$

### 1.3.4 Momentum Balance

The static pressure drop is determined from the Ergun equation (eq.1.18) as follows (Claudia *et al.*, 2014).

$$\frac{\partial P}{\partial z} - 150v \frac{(1 - \varepsilon_{bed})^2 u}{{\varepsilon_{bed}}^3 {d_p}^2} - \frac{1.75(1 - \varepsilon_b)\rho|u|u}{{\varepsilon_b}^3 d_p} = 0 \qquad \ldots 1.18$$

### 1.3.5 PSA Performance Indicators

Quantification of performance for PSA systems is the tedious task in comparing various process alternatives and design options for PSA systems. In this aspect, the knowledge of capital and operating costs provides an accurate account of the monetary value associated with the plant installation and operating feature. Also, other than detailed information of the pricing and manufacturing data involves measuring other important indicators such as recovery, purity and productivity. Product purity is usually set by the customer requirements while recovery is to be maximized at the specified purity levels. In most of the PSA systems, this leads towards a trade-off situation as design changes to improve product recovery adversely effects the system purity (Harish *et al.*, 2011).

$$Product\ recovery = \frac{Amount\ of\ components\ (hydrogen)\ in\ the\ product\ stream}{Amount\ of\ component\ in\ the\ feed\ stream} \qquad \ldots 1.19$$

$$Product\ purity = \frac{Amount\ of\ component\ (hydrogen)\ in\ the\ product\ stream}{Total\ amount\ of\ product\ stream} \qquad \ldots 1.20$$

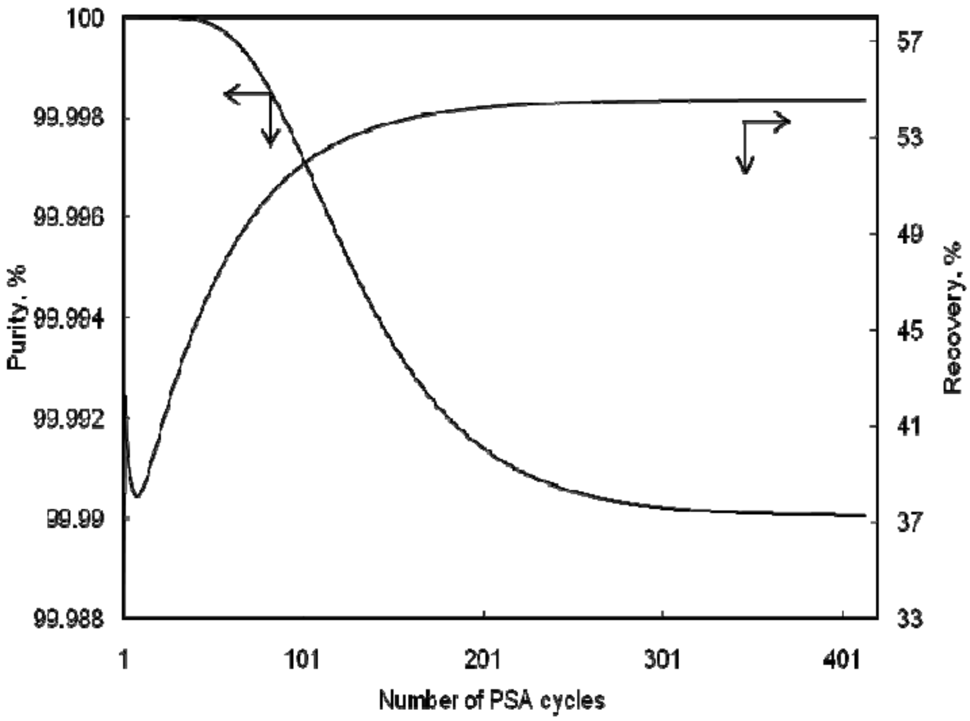



**Fig 1.5: Variation of hydrogen purity and recovery with each PSA cycle for the base case PSA.**

## 1.4 PROPYLENE DRYER UNIT (PDU) PROCESS:

PDU project will facilitate removal of moisture and filter the chemical grade propylene produced from the propylene recovery unit. Propylene recovery unit is designed to produce approximately 1,00,000 TPA of 95 wt. % pure chemical grade propylene from cracked LPG streams (95% recovery of propylene from the Feed). The dryer system installed prior to condensation consists of two adsorption columns within the in situ regeneration facility of closed loop nitrogen type. Propylene feed is pumped to the normal flow rate at the required pressure and temperature from C3 product pump to the bottom of the adsorption columns and dry propylene is recovered from the top. The dry propylene from the top of the column is then routed through the dust filter for removal of surplus particulates. Alteration of filters is done manually following the verification of its pressure drop. For filter changeover, propylene is discharged through PSV bypass valves to flare and then, nitrogen is purged with hose connections.

In case of normal moisture is feed, the adsorption cycle time would be 48 hours. When one column is under adsorption, the other column is utilized for regeneration. Draining of process liquids from column under regeneration from bottom is done by routing propylene vapors at controlled temperature and pressure from the top for 1 hour. Propylene vapors for this purpose are generated by passing feed through a vaporizer (which is heated by LP steam). During this phase, net feed to the column under adsorption cycle at a particular flow rate inclusive of the transferred quantity. First stage of depressurization is done gradually to fuel gas network over next 15 minutes, controlled by upstream pressure. PSV is provided on fuel gas line with discharge to flare gas line. Final depressurization is done to flare over next 5 minutes.

It is required to remove propylene from adsorption column before it is taken for heating so as to prevent polymerization and choking over adsorbent surface. Propylene vapors are taken off from the bed is accomplished by passing required quantity at 40$^{\circ}$C in an open loop from the bottom to top and releasing the vapors from top to flare line over the next 40 minutes.

Heating of bed for desorption of water by convection to 200$^{\circ}$C top and 180$^{\circ}$C bottom temperatures with hot $N_2$ in a closed loop is carried out over the next 13 hours. Heater will be a 180 KW electric heater and its outlet temperature is ramped up slowly at 5$^{\circ}$C per minute. Nitrogen is finally heated to 235$^{\circ}$C, passed through column from top to bottom, cooled by cooling water in Regeneration Gas Cooler, free water is separated in Water separator and then recirculated with blower. Make up $N_2$ is fed to the suction of blower at a regulated pressure through a PCV to compensate for $N_2$ losses across the entire loop. Bed heating is performed from top to bottom i.e., in counter-current direction to adsorption. Since, $N_2$ is used in a closed loop, loss of $N_2$ is very low and it is estimated to be less than 1% of the blower flow.

In the open loop purge step, pure $N_2$ is routed in an open loop for 1 hour from top to bottom. Dry $N_2$ in open loop aids desorption of residual water from hottest section at top of the bed and also fill bed voids with very dry $N_2$. Blower and electric heater are kept off during this step. Cooling of bed over the next 7 hours is achieved up to 40-50$^{\circ}$C by closed loop nitrogen with electric heater OFF and heater bypassed in the closed loop. Cooling is taken place from bottom to top (i.e., co-current direction) to avoid exposure of moisture on the dry zone of the bed at the top. Nitrogen passes through the adsorption column and then cooled by cooling water in Regeneration Gas Cooler, then routed to Water separator, blower filter and then recirculated with blower. Bed is isolated and kept in $N_2$ environment for 24 hours. A small flow of propylene liquid is brought in the column from bottom and column gets pressurized and filled up with liquid in over 30 minutes. Residual $N_2$ is discharged from the column to the flare over initial 5-10 minutes.

Both adsorption columns are run in parallel for 30 minutes in order to stabilize operations. During parallel run only required valves are kept open. Column will be then ready for change over and full feed liquid can enter the assigned column. Columns are changed over automatically with pneumatically operated isolation valves.

# 1.5 COST ESTIMATION TOOLS:

Aspen HYSYS comprises various range of components, grants an exceptionally powerful methodology to steady state modeling. Aspen HYSYS typically comprises of several key aspects which have been designed specifically to maximize the engineer's efficiency in adopting simulation technology. The single model ideology is key not only to the only engineer's efficiency, but to the efficiency of an organization. Aspen HYSYS used the concept of the fluid package to contain all the necessary information for performing flash and physical property calculations. This approach allows defining all the information (property, package, components, hypothetical components, interaction parameters, reactions, tabular data, etc.) inside a single entity. There are four key advantages to this approach:

i. All associated information is defined in a single location, allowing for easy creation and modification of the information.
ii. Fluid packages can be stored as completely defined entities for use in any simulation.
iii. Component lists can be stored out separately from the Fluid Packages as completely defined entities for use in any simulation.
iv. Multiple Fluid Packages can be used in the same simulation. However, they are defined inside the common Basis Manager.

The Simulation Basis Manager is property view that allows you to create and manipulate multiple fluid packages or component lists in the simulation.

## 1.5.1 Selection of Thermodynamic Model:

Elliott and Lira *(1999)* suggested a decision tree as shown in Fig.1.6

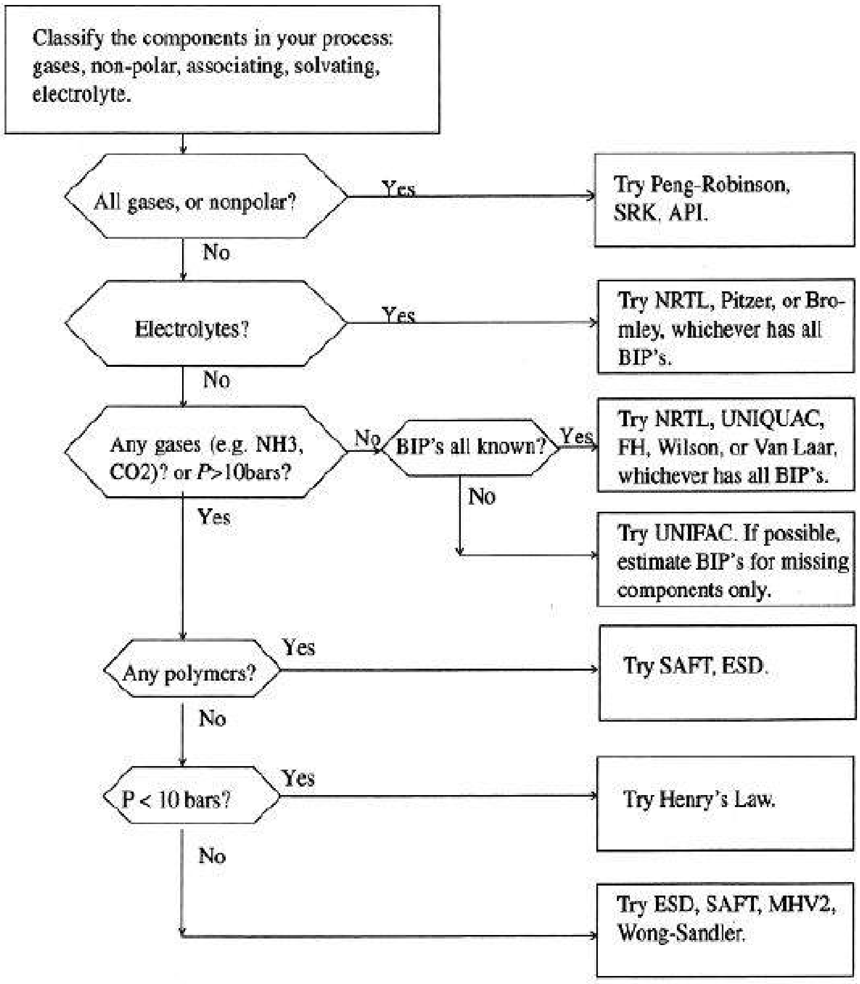



**Fig 1.6: Property Package Decision Tree (Mohd. Kamaruddin *et al.,* 2007)**

The property packages available in HYSYS allow predicting properties of mixtures ranging from well defined light hydrocarbon systems to complex oil mixtures and highly non-ideal chemical systems. The following Table 1.1 lists some typical systems and recommends correlations.

**Table 1.1: Recommended Properties for various process systems (Mohd. Kamaruddin *et al.*, 2007)**

| TYPE OF SYSTEM | RECOMMENDED PROPERTY METHOD |
|---|---|
| TEG Dehydration | PR |
| Sour Water | PR, Sour PR |
| Cryogenic Gas Processing | PR, PRSV |
| Air Separation | PR, PRSV |
| Vacuum Towers | PR, PR Options, GS (<10 mmHg), Braun K10, Esso K |
| Ethylene Towers | Lee Kesler Plocker |
| High Hydrogen Systems | PR, ZJ or GS |
| Reservoir Systems | Steam Package, CS or GS |
| Hydrate Inhibition | PR |
| Chemical Systems | Acitivity Models, PRSV |
| HF Alkylation | PRSV, NRTL |
| TEG Dehydration with Aromatics | PR |
| Hydrocarbon systems where Water solubility in Hcis important | Kabadi Danner |
| Systems with select gases and light HC | MBWR |

Note: PR=Peng-Robinson; PRSV=Peng-Robinson Stryjek-Vera; GS=Grayson-Streed; ZJ=Zudkevitch Joffee; CS=Chao-Seader; NRTL=Non-Random-Two-Liquid

The Peng-Robinson EOS (PR) is generally the recommended property package for oil, gas and petrochemical applications.

### 1.5.2 Economic Evaluation Tools:

Economics in Aspen involves three software systems: The process simulator (Aspen HYSYS V8.6) and the economic evaluation software (Aspen Process Economic Analyzer V8.4 and Aspen Capital Cost Estimator V8.4). Both the economic software is integrated by embedded in the process simulator.

The tool Aspen Process Economic Analyzer V8.4 (Aspen PEA) provides the facility of mapping, sizing and estimates the cost for process equipments directly from the simulator; whereas, the Aspen Capital Cost Estimator V8.4 (Aspen CCE) generates both conceptual and detailed cost estimates of the overall plant. Aspen PEA is the predecessor to Aspen CCE and it claims to have proven, field tested, industry-standard cost modeling and scheduling methods. Aspen PEA is designed to generate both conceptual and detailed estimates.

The capital cost is the investment that is put in to build or expand the plant. Aspen CCE is a model-based estimator, which, according to AspenTech, employs a sophisticated “volumetric model" rather than a factor-based model. Aspen CCE uses cost models to prepare detailed lists of costs of process equipment and bulk materials.

During the design process, it is nearly impossible to know the exact quantity of this investment. This is why it is important for the engineers and project managers to get as close to the actual value possible.

Several sources classify capital cost estimates into five classifications. These classifications are as follows: preliminary estimates, definitive estimates, study estimates, order-of-magnitude estimates and detailed estimates. Each classification requires a different level of information and preparation. Table 1.2 below shows an example of this classification in a matrix. Order-of-magnitude estimates usually rely on cost information for a complete process. This information is usually taken from previously built plants. This cost information is scaled using scaling factors for capacity and inflation. This estimate is also called the ratio or feasibility estimate and usually requires a block diagram. Although the most accurate way to estimate the purchase cost of a piece of equipment is to obtain a current price quote from the appropriate vendor. The next immediate alternative would be to utilize cost data from earlier purchased equipment of the exact type. Based on previous cost database, the current cost of equipment could change based on differences in the equipment capacity and also differences in time.

The cost elements governing the economic evlauation of a project are as follows:

- → Cost indexes are applied to update costs from the originated time to the present times. Cost indexes are used to give a general estimate but cannot take into account all factors. There various commonly applied cost indexes depending on the category of project,a mong which the Marshall and Swift equipment cost indexes and the Chemical Engineering plant cost index (CEPCI), provides very similar outcome and are suggested for use with chemical-plant investment estimates and process-equipment estimates. Aspen PEA and Aspen CCE V8.4 follows 2014 data, where the CEPCI was found to be 580.22 (CHE, 2014).
- → Contingency percentage specifies allowance for contingencies of the bare plant cost. This field depends on the selection made for the following fields in the standard basis file: i. Process Description, ii. Process Complexity and iii. Project type. This information is used to reflect the desired project design methodology.

- → The simulator Units of Measure specification are used in mapping simulator units to Aspen CCE units, serving as the cross reference. Aspen PEA and Aspen CCE provides a set of common simulator units and it facilitates provision for modification and addition of units to these files. When the simulator output is loaded, Aspen CCE identifies all units of measure in the file. Any units not mapped in the project's current simulator, cross reference unit of measure specification will be automatically added to the list.
- → The default country base is US and the default currency is Dollars (USD). Changing the country base automatically changes the currency to that country base. The conversion rates taken by Aspen PEA V8.4 and Aspen CCE V8.4 are given in Fig. 1.7
- → Wage rate is the amount of base wage paid to a worker per unit of time (as per hour or day) or per unit of output if on piecework. In Aspen PEA and Aspen CCE, to increase or decrease wages for all disciplines under the selected phase, enter the percentage of the base wage rate. For eg., entering "200" would double the wage rates, entering "50" would cut wage rates in half. The General Wage rates information defines wage rates, productivities, and overtime for all techniques in a workforce.
- → An investment analysis conducted on any process needs to provide an accurate figure for total project expenditure. Since operating costs are ususally a large part of this cost, it is important to accurately account for all raw materials consumed in the process. The general investment parameters that drive the investment analysis to be mentioned are period description, number of periods for analysis, tax rate, desired rate of return, depreciation method and many more.
- → As this default contingency could not be set according to the desired project estimation and could be considered during decisive evaluation of the project, it was not considered during the preliminary capital estimation. Table 5.5 gives the depth of guidelines to decide on project contingency.

**Table 1.2: AACE Guidelines for Process Contingency (James Black *et al.*, 2013)**

| Technology Status | Process Contingency (% of Associated Process Capital) |
|---|---|
| New concept with limited data | 40+ |
| Concept with bench-scale data | 30-70 |
| Small pilot plant data | 20-35 |
| Full-sized modules have been operated | 5-20 |
| Process is used commercially | 0-10 |

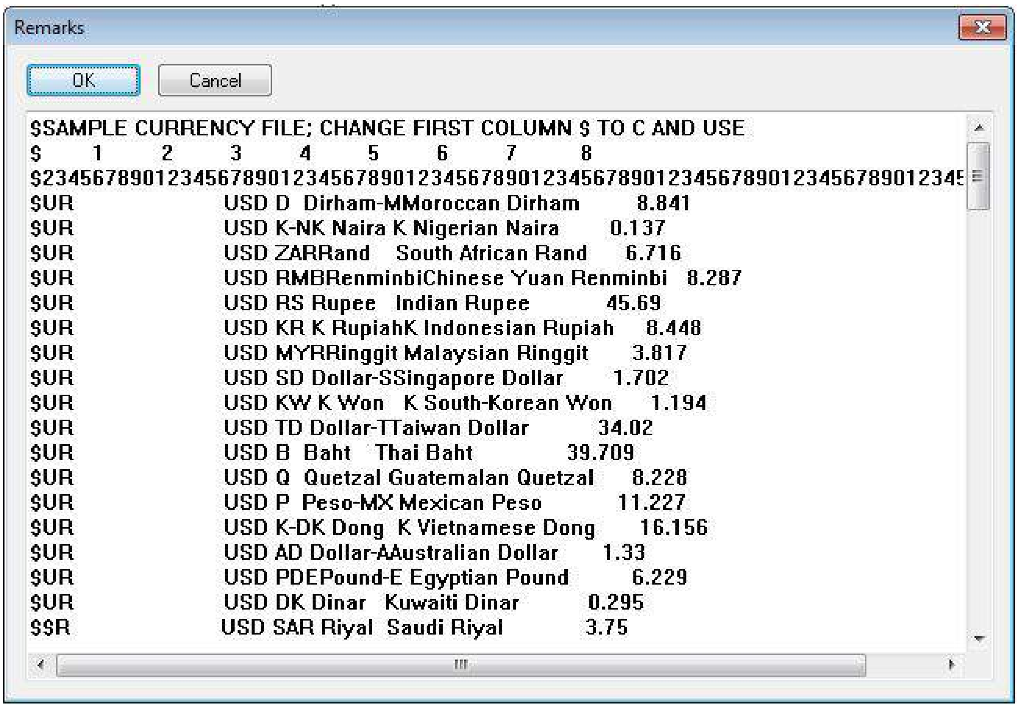



**Fig 1.7: Conversion Rates as on Aspen PEA V8.4**

**Table 1.3: Cost estimate classification matrix for process industries (Symister *et al.*, 2016)**

| | *Primary Characteristic* | *Secondary Characteristic* | | |
|---|---|---|---|---|
| **Estimate Class** | **Percent of project Completion** | **Purpose of estimate** | **Methodology** | **Expected Accuracy range** |
| **Class 5** | 0% to 2% | Concept Screening | Capacity factored, parametric models, judgement, or analogy | L: -20% to 50% H: +30% to +100% |
| **Class 4** | 1% to 15% | Study or feasibility | Equipment factored or parametric models | L: -15% to 30% H: +20% to +50% |
| **Class 3** | 10% to 40% | Budget authorization or control | Semi-detailed unit costs with assembly level line items | L: -10% to 20% H: +10% to +30% |
| **Class 2** | 30% to 75% | Control or bid/tender | Detailed unit cost with forced detailed take-off | L: -5% to 15% H: +5% to +20% |
| **Class 1** | 65% to 100% | Check estimate or bid/tender | Detailed unit cost with detailed take-off | L: -3% to10% H: +3% to +15% |

Turton *et al.*, and other authors in various texts, gives the relationship between purchased cost and an attribute related to units of capacity:

$$\frac{C_a}{C_b} = \left(\frac{A_a}{A_b}\right)^n \qquad \text{... 1.21}$$

, where A is the equipment cost attribute; $C$ is the purchased cost and n is the cost exponent. The subscripts *'a'* and *'b'* refers to the equipment with the required attribute and equipment with the base attribute respectively. The value of the cost exponent varies based on the equipment. The value of the cost exponent *'n'* is, however, around 0.6.

If cost data is collected from previous years, the cost forecast for current year and years as well as upcoming years will be different due to factors such as inflation. To account for this change, cost indexes are used. *Turton* also gives the following relationship:

$$C_2 = C_1\left(\frac{I_2}{I_1}\right) \qquad \text{... 1.22}$$

, where $C$ is the purchased cost, $I$ is the cost index. 1 and 2 refers to the based time when cost is known and the time when cost is desired, respectively. Likewise, the same procedure has been followed in this report.

Also, for the Lang factor technique, the total capital cost is determined by the product of the total purchased cost and a constant known as the Lang factor. The equation is as follows:

$$C_{TM} = F_{Lang} \sum_{i=1}^{n} C_{p,i} \qquad \text{... 1.23}$$

, where $C_{TM}$ is the capital cost of the plant; $C_{p,i}$ is the purchased cost of the major equipment units; $n$ is the total number of units and $F_{Lang}$ is the appropriate Lang factor. This technique, unfortunately, does not account for special changes in the process such as materials of construction and high operating pressures.

In *Towler and Sinnott*, the Fixed Capital Investment (FCI) is given as an inside battery limits (ISBL) – which is the cost of the plant itself including:

i. Equipment purchase cost
ii. Equipment erection, including foundation and minor structural work
iii. Piping, including insulation and painting
iv. Electrical, power and lighting
v. Instruments and automatic process control (APC) systems
vi. Site preparations

*Towler and Sinnott* agree with Turton *et al.*, when it comes down to the classification of cost estimates as both literature sources use the classification put forward by the Association for the Advancement of Cost Estimating (AACE International).

*Towler and Sinnott,* however, puts forward a different correlation in order to calculate purchased equipment costs. These correlations are in the form of the below equation:

$$C_e = a + bS^n \qquad \text{... 1.24}$$

, where $C_e$the purchased equipment is cost; $a$ and $b$ are constants, $S$ is the size parameter, and n is the exponent for that type of equipment.

Compared to all the above methods mentioned, Aspen CCE provides a detailed breakdown of each individual item that contributes to the cost of the piece of equipment. The program is also able to account for more detailed specifications which, consequently and intuitively, will make the estimate more precise than the factor-based methods. It shows all the design data used in the cost engine as well as summary of all the installation costs and estimated man hours needed and the cost for those man hours.

When compared to the Aspen CCE, for most of the equipment, both *Turton's* module costing method and *Towler and Sinnott's* factorial method was within the -30 to 50% margin of error as laid out by the AACE for class 4 estimates. *Turton's* method had an average exponent of 0.63, while *Towler & Sinnott's* method and Aspen CCE had an average exponent of 0.55 and 0.41, respectively. Aspen CCE is so detailed in its cost reports that using it as a benchmark in the other methods are justified.

In the later stages of the project design, when detailed equipment specifications are available and firm quotations have been obtained, an accurate estimation of the capital cost of the project will be obtained through the above procedure.

# CHAPTER 2
# PROJECT SCOPE AND OBJECTIVE

## 2.1 OBJECTIVE:

The main objective of this guide is to provide guidance that should improve the quality of cost estimates supporting execution of projects and program. The cost estimating principles and processes provided herein may be used to meet or adhere the organization's requirement while utilizing the industry standards and best practices. The flow procedure is to develop process simulation model for the given process and building up of standard documentation by generation of cost estimation for budgetary estimate quotes of tenders.

## 2.2 SCOPE:

i. Development of process model and cost evaluation.
ii. To generate in-house database of various elements such as bought out and fabrication items like equipments, instruments, structure piping, civil works, etc.
iii. Generation of cost estimation calculation sheet and documentation, which will be a part of BEDP (Basic Engineering Design of Project).

# CHAPTER 3
# REVIEW OF LITERATURE

The EIA and RRA report and study for expansion of HPCL Mumbai Refinery by Engineers India Limited (2016), accounted that through the progressive capacity expansions, current crude oil processing capacity of HPCL Mumbai Refinery is 7.5 MMTA. It currently has two trains of primary distillation units (CDU I & II), secondary processing facilities viz. FCCU's, DHDS, MS block, LOBS production facilities and other associated treating and utility facilities. With the installed facilities, the refinery shall be able to produce gasoline oil and diesel meeting Euro IV quality specifications, besides other petroleum products like LPG, Naphtha, Kerosene, ATF, fuel oil and sulphur. HPCL intends to increase the refining capacity of its Mumbai refinery 9.5 MMTA including Propylene Recovery Unit (PRU) and revamp of Captive Power Plant (CPP). The basic process of PRU on this report described that the cracked LPG will directly come from the LPG Testing Unit and shall be fed into the PRU through a feed surge drum without considering any intermediate storage. A line will be laid down from PRU to existing bullets for storage of products. Debutanizer bottom and Propane/Propylene splitter bottom will be rich in Propane and C4+ which is considered as the by-product of PRU. These bottom streams (Propane and C4+) will be routed to LTU unit where these shall be mixed with existing LPG stream to LPG bullets. Two existing mounded bullets (Storage capacity: 1768 $m^3$ each), designed for LPG/propylene are to be used to store propylene product from PRU unit. Three (2W+1S) new loading pumps are considered to load the propylene in tankers.

Dragon Nikolic *et al.*, (2007) stated that the motivation of their work in PSA domain was increasing demand for $H_2$, particularly in petroleum refineries and in the petrochemical processes (99.99+ %). Since hydrogen is adsorbed much less than almost any other components, PSA has a clear advantage over almost all other possible approaches according to the investigation of author. The author declared the result of their study with high $H_2/CO_2$ purity and recovery comparable to the original process, good quality tertiary product (suitable for fuel gas) and lower capital cost. The clarification for lower capital cost given by author was due to lower number of beds and the proposed PSA cycle configurations exhibit comparable performance with the conventional cycles at a lower capital cost.

Given the sequence of process steps, the graphical approach by Ritter *et al.*, (2010) can be used for complex PSA cycle scheduling. This graphical framework divided the total cycle time into a set of unit cells such that the duration of any process step occupies one or several unit cells. The approach could generate all possible multi-bed systems with a given sequence of steps; even delay steps will be enforced appropriate to synchronize the beds.

Linde's current facility of PSA process has seen gigantic development amid the most recent decades for the most part due to its effortlessness and low working expense. Significant applications have been the recuperation of high virtue hydrogen, methane and carbon dioxide and in addition the era of nitrogen and oxygen. Moreover, it has picked up significance for the mass expulsion of carbon dioxide from direct lessening top-gases. Linde as the world leader in adsorption technology has designed and supplied more than 500 PSA plants, including the world's largest units and units with highest availability. The PSA process works at basically constant temperature and uses the effect of alternating pressure and partial pressure to perform adsorption and desorption. The PSA process consequently allows the economical removal of large amounts of impurities.

Robert *et al.,* (2000) developed a base model cost of the process and the product ethanol through NREL approach (Fig 3.1).

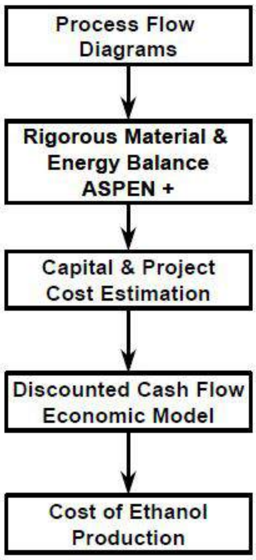



**Fig 3.1: NREL's approach to process design and economic modeling (Robert *et al.*, 2000)**

The first was to develop the preliminary PFD. For those parts of the procedure that depend on new innovation, the authors depended on the examination that has been finished and any improvement efforts that had been accomplished exceptional. After the process flow diagram was sketched out, they began the development of a process model using Aspen Plus/Aspen HYSYS simulator. A simulator such as Aspen Plus/Aspen HYSYS has the thermodynamic models, and rigorous unit operation models in-built, so there was no need for the authors to program them. The simulator easily handled complex processes with solids. Very importantly, a simulator was found to be self-documenting and easily understood by anyone knowledgeable in the software. The authors declared that this was commercially supported and widely accepted by the process industries. Development of the Aspen Plus/Aspen HYSYS model involves using all information available. While the Aspen Plus/Aspen HYSYS model was completely rigorous in its mass and energy balance calculations, it was not completely predictive. They at times did more detailed modeling in either stand-alone Aspen Plus/Aspen HYSYS models and translated that information to the complete Aspen Plus/Aspen HYSYS model through a simpler, generally empirical form. They used this approach for complex kinetic models, agitator power models and some distillation optimization. Once the mass and energy balance model was complete, the process equipments were costed. For the base case, they sized each piece of equipment using spreadsheets, sometimes Aspen Plus/Aspen HYSYS or other software. Now and again, they could get equipment vendor to size and supply a cost appraise. This was critical for some of the unusual equipment in the process. So, when they had no other source of a cost estimate, they used the Icarus Corporation estimation software (Aspen Process Economic Analyzer and Aspen Capital Cost Estimator). The information for database containing information about scaling of costs that included the scaling exponent for the eq.3.1 below:

$$New\ Cost = Original\ Cost\ \left(\frac{New\ Size^{*}}{Original\ Size^{*}}\right)^{exp} \qquad \ldots 3.1$$

* or characteristic linearly related to the size.

In addition to all the numeric field data contained in the cost database, they have also included a document that describes in complete detail the design and cost calculations that were performed for that piece of equipment. If a vendor cost quotation exists, it was included. If the calculation was performed in another software package, the results from the program were included. Everything they ever needed to understand the design and cost of that piece of equipment was stored there. The overall complete economic analysis model developed by them is shown in Fig 3.2.

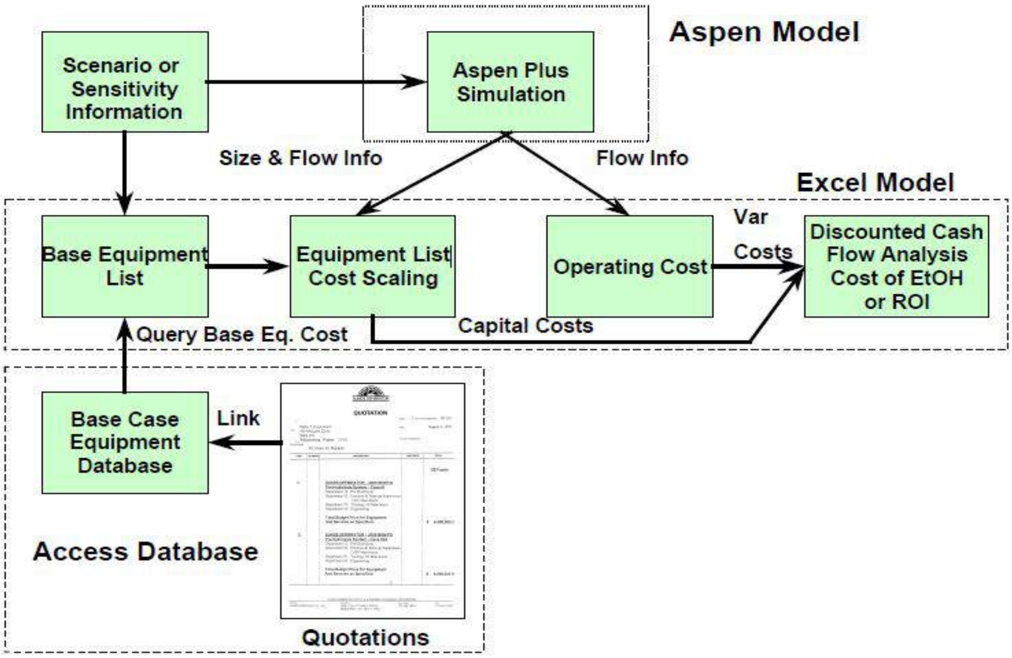



**Fig 3.2: Complete Economic Analysis Model (Robert *et al.*, 2000)**

Mohd. Kamaruddin Abd Hamid (2007) accounted that Aspen Hysys is a powerful engineering simulation tool that has been created with respect to the engineering capabilities and other interactive operations. The reasons for primary choice of Aspen Hysys are i. it defines a fluid package, ii. it adds streams and separators and iii. performs simple flash calculations. Aspen Hysys used the concept of the fluid package to contain all necessary information for performing flash and physical property calculations. Aspen Hysys provides enhanced equations of state (Peng-Robinson and PRSV) for rigorous treatment of hydrocarbon systems, semi-empirical and vapor pressure models for the heavier hydrocarbon systems, steam correlations for accurate steam property predictions, and activity coefficient models for chemical systems. For oil, gas and petrochemical applications (TEG dehydration, cryogenic gas processing, air separation, atmospheric crude towers, vacuum towers, high $H_2$ systems, hydrate inhibitions etc.), the Peng-Robinson EOS (PR) is generally the recommended property package.

Dimitrou *et al.*, (2015), estimated the capital and operating costs for each $CO_2$ utilization (CCU) process concept using the software Aspen Process Economic Analyzer (APEA) which, like Aspen Plus, is licensed by Aspen Technology. They linked the APEA to Aspen Plus to estimate costs by utilizing the output results of the Aspen plus simulations. The default country of project was set by them as UK, which defines several economic parameters in APEA, such as currency, salary rates, equipment costs and construction materials. The capital investment comprises of installed equipment costs, indirect costs, tax and working capital. This paper includes the capital costs of the PSA unit and the FT off-gas combustion in the estimated capital investment of the RWGS and FT synthesis section.

Ling Tou *et al.,* (2013) analyzed that process economic analysis includes a conceptual level of process design to develop a detailed process flow diagram, rigorous material and energy balance calculations (via commercial simulation tools, Aspen Plus, Aspen Hysys), capital and project cost estimation (CAPEX and OPEX), a discounted cash flow economic model, and the calculation of a minimum butanol or ethanol selling price.

Omar Joel Symister., (2016) stated that Aspen Capital Cost Estimator (Aspen CCE) is a model based estimator which, according to AspenTech, employs sophisticated "volumetric model" rather than a factor-based model. Aspen CCE used cost models to prepare detailed list of costs of process equipment and bulk materials. They recorded the pricing changes in Aspen Icarus Evaluation Engine for V8.6 (2013 basis) to V8.8 (2014 basis) that may be found in the help menu of the software. The changes included:

- a 2.7% decrease to a 0.8% increase in equipment costs
- a 3.3% decrease to a 5.6% increase in piping costs
- a 0% to 4.4% increase in civil engineering costs
- a 1.3% decrease to a 3% increase in steel costs
- a 7.5% to 13.8% increase in instrumentation costs
- a 0.3% to 2.3% decrease in electrical costs
- a 3.1% decrease to 1.7% increase in insulation costs
- a 0.5% to 0.9% increase in paint costs
- Carbon steel plate pricing had an approx. 8% increase
- 305 stainless steel plate pricing had an approx. 2% decrease while tubing had a 17% decrease.

According to this investigation of software, the author stated that "these results were obtained by running a general benchmark project containing a representative mix of equipment found in a gas processing plant. In addition to pricing changes, model enhancements and defect corrections have affected overall percentage differences".

# CHAPTER 4
# METHODOLOGY

The tools adopted here are as follows:

i. Aspen HYSYS V8.6
ii. Aspen Process Economic Analyzer V8.4
iii. Aspen Capital Cost Estimator V8.4

The schematic flow (Fig 4.1) shown below gives the basic outline of the methodology followed for capital cost estimation of PSA and PDU units.

## 4.1 Overview of Methodology:

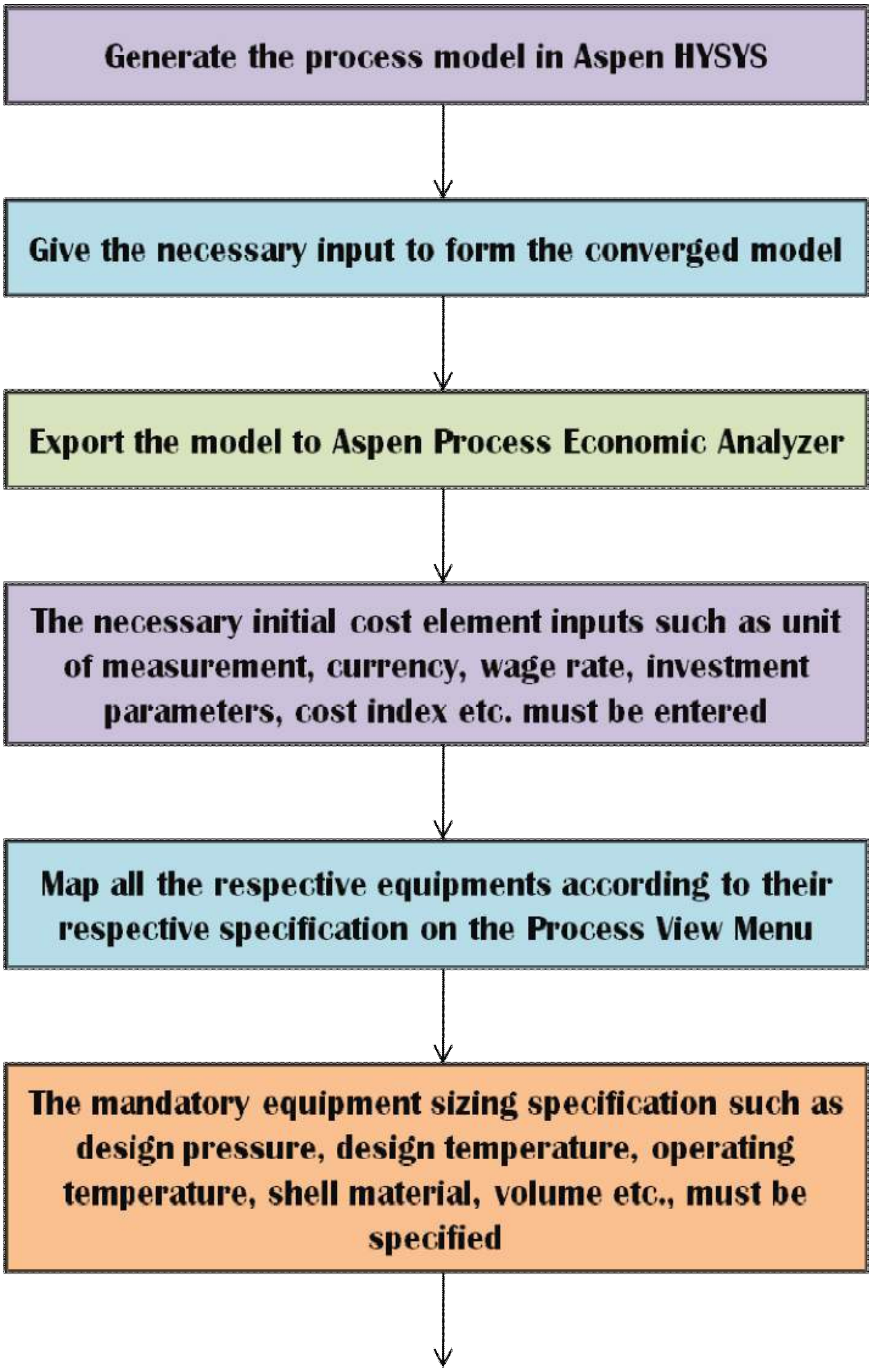
Conventionally, it is pursued to transfer the simulation results of Aspen HYSYS into Aspen Process Economic Analyzer. This could be achieved by selecting Send to Economics -> Aspen Process Economic Analyzer through the Economics section of the Aspen HYSYS menu bar. The simulation results will be loaded automatically into Aspen Process Economic Analyzer. Having completed the initial setup such as entering the Project Name, Project Description, Unit of Measure, Currency, Design Criteria, Investment Parameters, Material Index and other necessary initial inputs, the next step will be to map the process simulation units into additional illustrative process equipment models (eg. RADFRAC model mapped through a reflux accumulator, condenser, tray tower, etc.; and also a HEATX simulation model mapped through a shell-and-tube as well as floating-head heat exchanger) and other related plant bulks, which comprises of induction items to mention some of them like piping, insulation, instrumentation, paint etc. Subsequently, Aspen Process Economic Analyzer carries the mapping and reserves accumulated for equipment sizes and the installation pieces need to be computed. Also, note that the equipment sizing as well as the mapping steps are supposed to be accomplished in line with costs and sizes of the installation materials anticipated throughout the course of Equipment Costing stage.

Each equipment of the simulator must be selected individually and endure the mapping steps correspondingly, in order to commence the mapping stage under the Process Economic Analyzer window. For columns such as Fractionating column, depropanizer, tray-type distillation column, packed bed column, adsorption column and others, every item should be mapped and sized sequentially, since the mapped components are checked-in with an indication, only after which the component will be fed for sizing stage. It may be favorable to map every process unit individually, when there would be multiple process units of a specific type. Two distillation towers, taken as outline and that vary in plate effectiveness, is mapped independently and the adjustment in the plate proficiency under Design Criteria before individual tower is mapped. For each simulator item, the default listing would show every corresponding equipment items in Aspen PEA.

Likewise, the mapping could be modified from a shell-and-tube heat exchanger with a fixed tube sheet to one with a floating bed, when a condenser is taken into account. After the desired mapping stages and modifications were finished, 'OK' option can be selected and if not wait for the equipment mapping and sizing to be completed. Whereas, for pumps such as reboiler pumps, centrifugal pumps and others, before proceeding to the mapping, it was fetched to the focus that the reboiler pumps are used usually with vertical reboilers but not with the kettle type reboilers. When accurate for adding, the already stated above, mapping procedure was followed.

During this stage, when each and every equipment items have been sized and initalized by Aspen PEA, whose calculations would be originated from the simulator data, and also the default values specified prior. Since each equipment would be activated by undertaking sizing step, it would appear in the Aspen PEA Main window in the form of list, known as the List Window. Next, Size Item is selected from the List Window by simply using the right click on all the equipment individually. The blank fields on the component specification form for Capacity, Design Temperature, Design Pressure, Operating Temperature, Shell Material, number of trays for columns, Diameter, Tangent-to-Tangent height, Pump Head, Pump % Efficiency, Hot Inlet stream, Cold Inlet stream, Hot Outlet stream, Cold Outlet stream, Surface area, Duty, and other mandatory specification required for sizing of the equipment. After the sizing inputs are entered, the installed cost of individual equipments can be evaluated through the option *Evaluate* present on the component specification form. A brief report generating the installed cost of each equipment individually would be the outcome of this evaluation. The purchased cost and installed direct cost of the equipment evaluated would be the content of this evaluated report. A complete report of the entire project could be generated by following the evaluating procedures for the capital estimates for the process, as discussed. This should be achieved by transferring the project from Aspen PEA to Aspen CCE, through few fine-tune phase. The detailed estimate will be generated in the Capital Estimate Report generated under the Bulk Material by Area Section and List of Equipment.

This way, all of the economic evaluation of the project through Aspen PEA and Aspen CCE can be produced from within the Aspen package tools opted for this task.



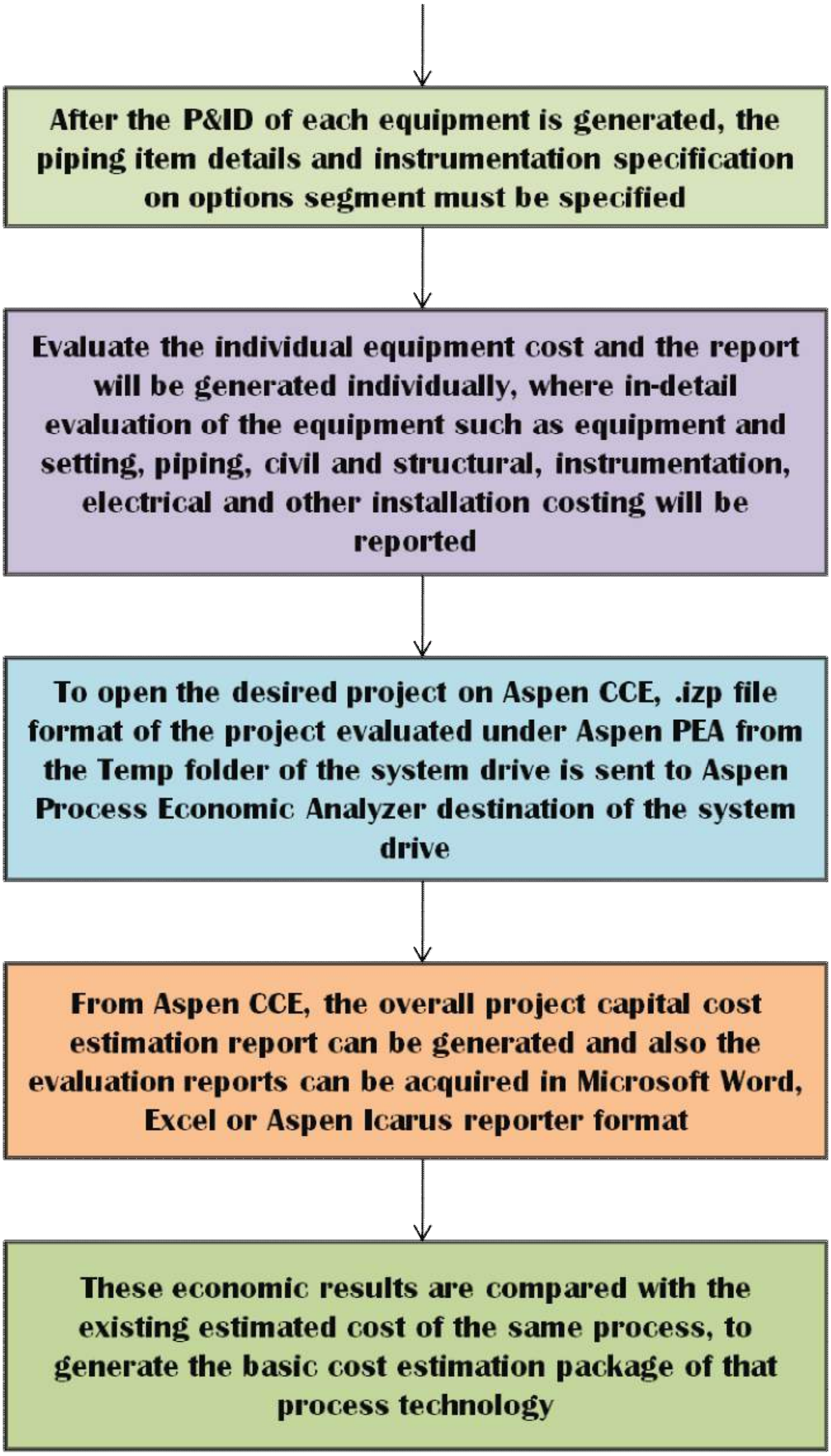



**Fig 4.1: Mechanism of Capital Cost Estimation**

For estimating the equipment sizes and cost estimate for a process model using Aspen PEA and Aspen CCE simulated with Aspen HYSYS, it would be required to generate the simulation reports for applying into Aspen PEA and Aspen CCE. Even as this was accomplished in the analogous manner for nearly all of the main process simulators, the following notes spots on the stages for preparing Aspen HYSYS simulation for PSA and PDU unit.

# CHAPTER 5
# RESULTS AND DISCUSSIONS

The following stages lead the steps followed for preparing Aspen HYSYS simulation for PSA and PDU units.

i. A New project for PSA model on Aspen HYSYS is created and the Component list was entered as shown on Fig 5.1 and Fig 5.2.

ii. Suitable fluid Package for the model has to be specified, as shown on Fig 5.3.

iii. After the above properties are mentioned, the model for PSA was generated on the Simulation section Fig 5.4. Under the PSA Model, the Palette Component Splitter was considered to represent an adsorber.

iv. The basic input stream condition (pressure, temperature, molar flow) has to be mentioned for each process equipment (Fig 5.5), component splits and the composition of the same has to be given (Fig 5.6)

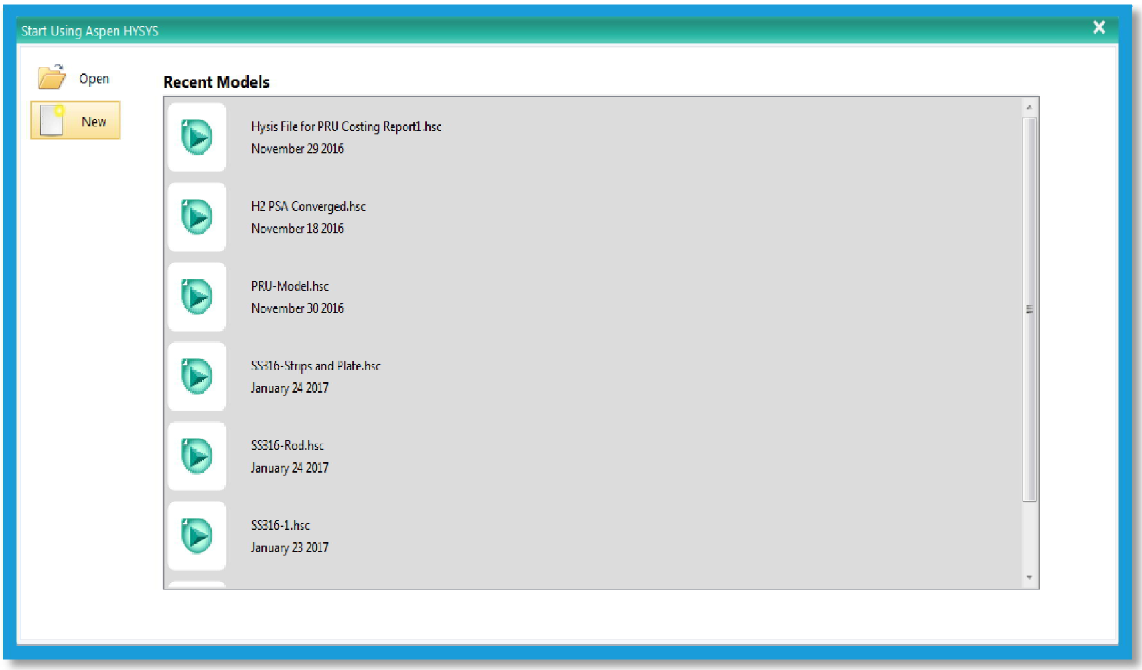



**Fig 5.1: New Project Menu on Aspen HYSYS**

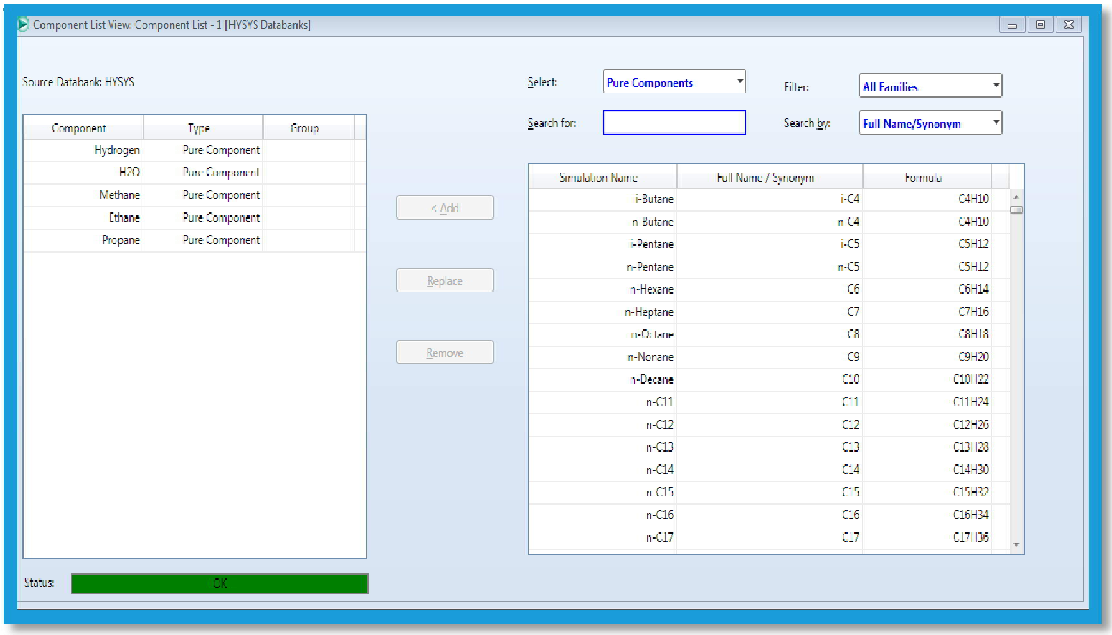



**Fig 5.2: Component List for PSA**

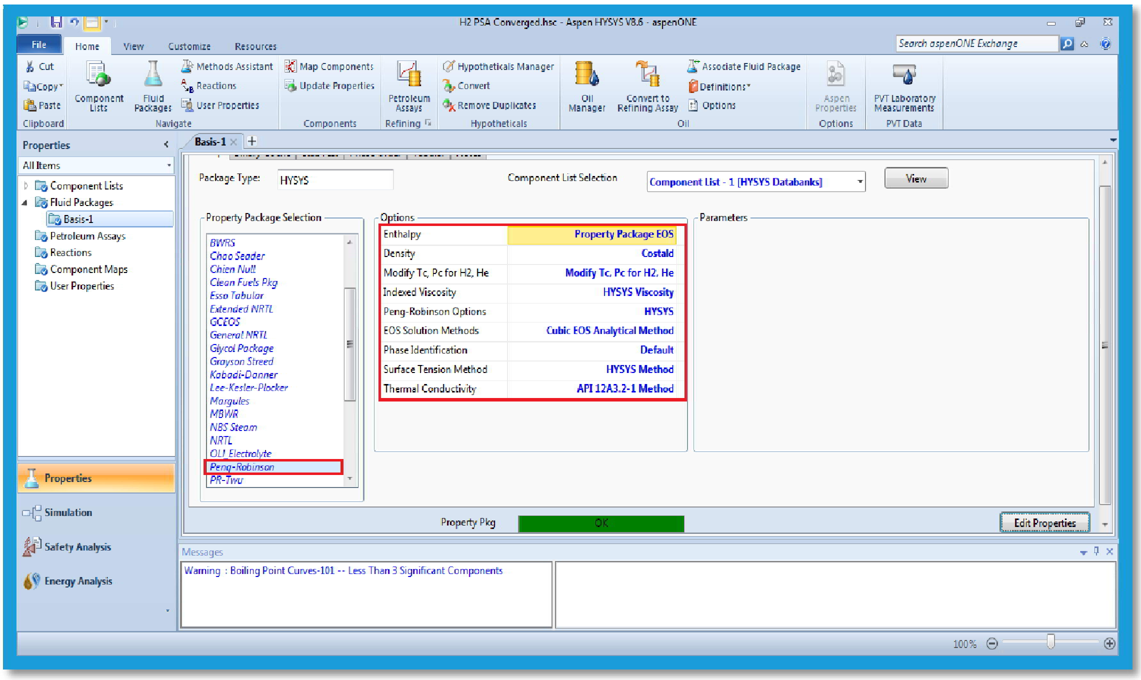



**Fig 5.3: Fluid Package for PSA**

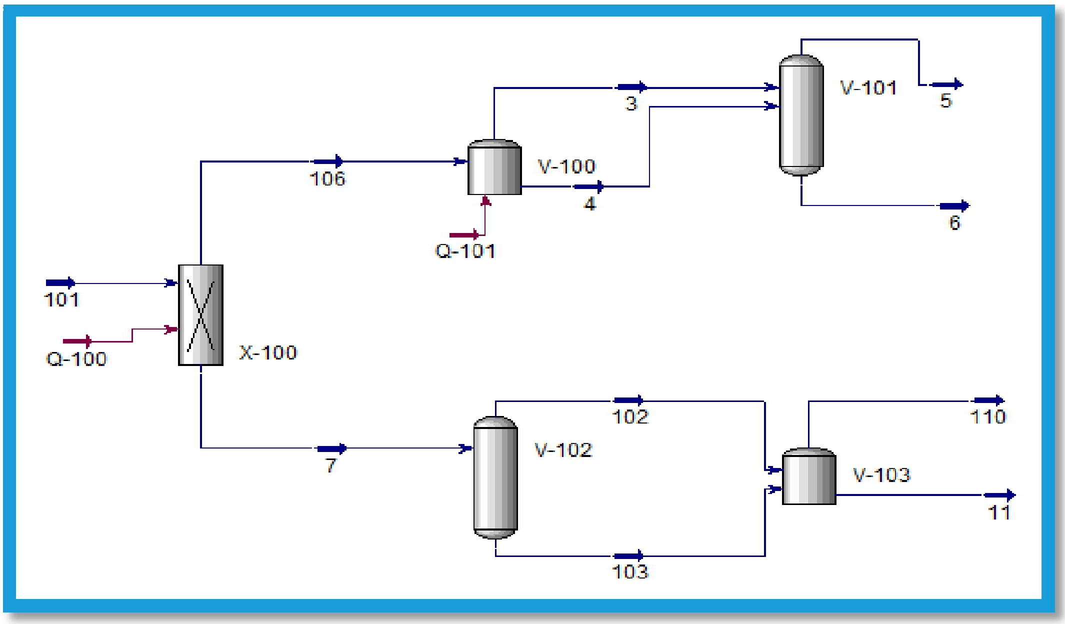
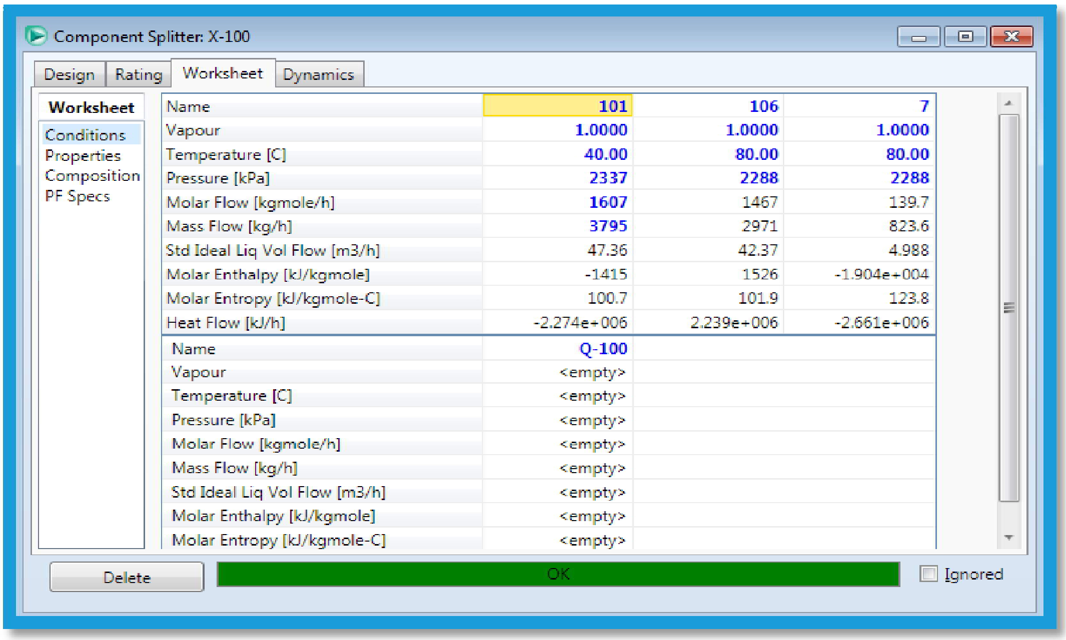



**Fig 5.4: Simulation Model of PSA on Aspen HYSYS**


Component Splitter: X-100

Design | Rating | Worksheet | Dynamics

Worksheet: Conditions, Properties, Composition, PF Specs

| Name | 101 | 106 | 7 |
|---|---|---|---|
| Vapour | 1.0000 | 1.0000 | 1.0000 |
| Temperature [C] | 40.00 | 80.00 | 80.00 |
| Pressure [kPa] | 2337 | 2288 | 2288 |
| Molar Flow [kgmole/h] | 1607 | 1467 | 139.7 |
| Mass Flow [kg/h] | 3795 | 2971 | 823.6 |
| Std Ideal Liq Vol Flow [m3/h] | 47.36 | 42.37 | 4.988 |
| Molar Enthalpy [kJ/kgmole] | -1415 | 1526 | -1.904e+004 |
| Molar Entropy [kJ/kgmole-C] | 100.7 | 101.9 | 123.8 |
| Heat Flow [kJ/h] | -2.274e+006 | 2.239e+006 | -2.661e+006 |

| Name | Q-100 |
|---|---|
| Vapour | <empty> |
| Temperature [C] | <empty> |
| Pressure [kPa] | <empty> |
| Molar Flow [kgmole/h] | <empty> |
| Mass Flow [kg/h] | <empty> |
| Std Ideal Liq Vol Flow [m3/h] | <empty> |
| Molar Enthalpy [kJ/kgmole] | <empty> |
| Molar Entropy [kJ/kgmole-C] | <empty> |

Delete | OK | Ignored

**Fig 5.5: Stream Conditions**

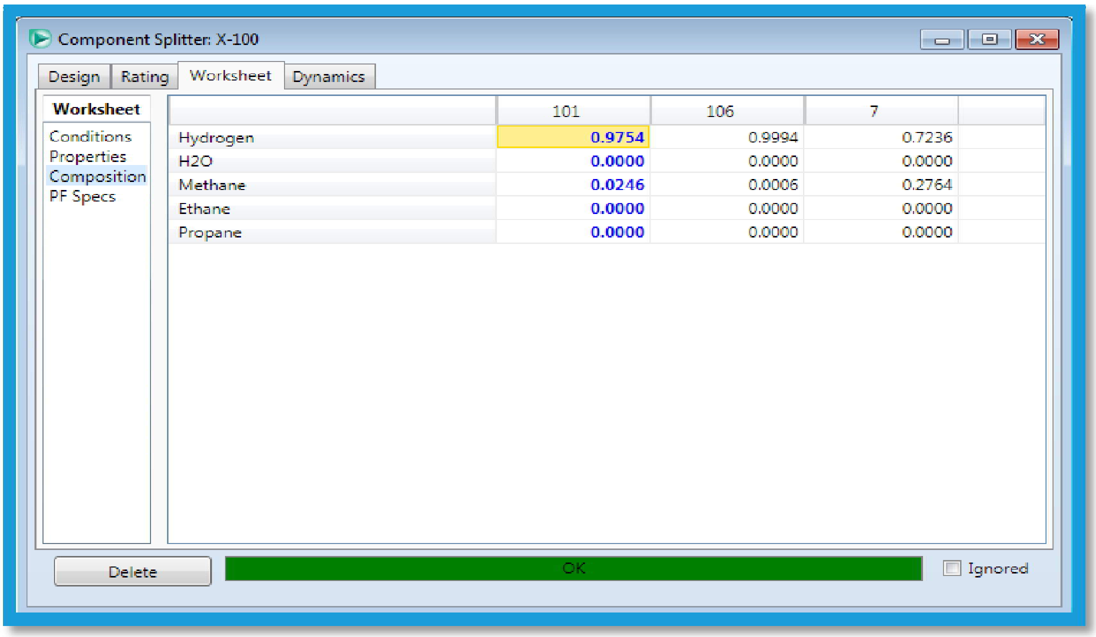



**Fig 5.6: Molar Composition of Streams**

It is usually important to achieve the simulation files in two ways. To begin with, in order to estimate equipment sizes, Aspen PEA and Aspen CCE ordinarily would require the evaluation of blend properties not required for the material and vitality adjust, and phase equilibria counts conveyed by the process simulators.

It is required to expand the simulation report files along with the estimates of mixture properties, such as thermal conductivity, surface tension and viscosity, for the streams of the simulation flowsheet.

Next, the Aspen PEA and Aspen CCE tools require detailed particulars to evaluate equipment sizes that are not worked out by few of the similarly working simulation models.

Now after the model was converged and the necessary Aspen PEA and Aspen CCE stream properties were added, the Aspen HYSYS simulation results are required to be exported into Aspen PEA (Fig 5.7). This is processed by selection of Send to Economics option under the File pull-down menu in Aspen HYSYS. The simulation generated is automatically generated into Aspen PEA.

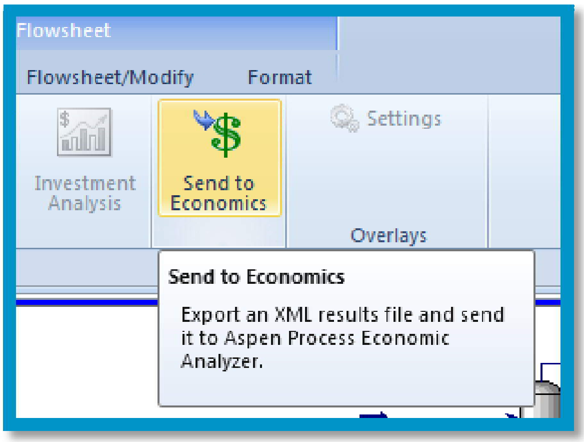



**Fig 5.7: Export of PSA model from Aspen HYSYS to Aspen PEA**

## 5.1 ECONOMIC EVALUATION OF PRESSURE SWING ADSORPTION (PSA):

After the simulation file is transferred to Aspen PEA from the Aspen HYSYS suite, it would be automatically appeared as well as commenced and the Create New Project box would emerge (Fig 5.8). The user can either mention a new Project Name or could choose an existing project to begin a new scenario. Even though the Project Name "H2 PSA Converged" was allotted automatically through the Aspen HYSYS file name, the new Project Name "PSA" and Scenario "PSA PEA" was entered. Also note the format of naming the scenario would permit underscore and space characters, but punctuation marks are not allowed. After selecting OK option, the first four dialog boxes appear are i. Project Properties ii. Input Units of Measure Specifications dialog box iii. General Project Data box and iv. Load Simulator Data? dialog box.

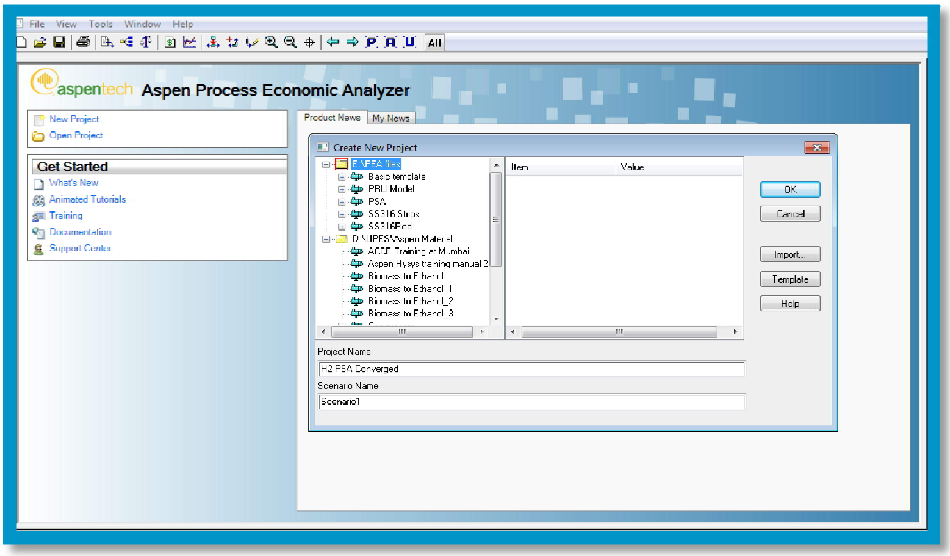



**Fig 5.8: Create New Project Menu on Aspen PEA**

The first Project properties dialog box (Fig 5.9), is the one among an option under the Project Description box, held with a section for noting down the remarks. A unit of measure option should also be chosen wherein; normally “Metric” option is to be selected.

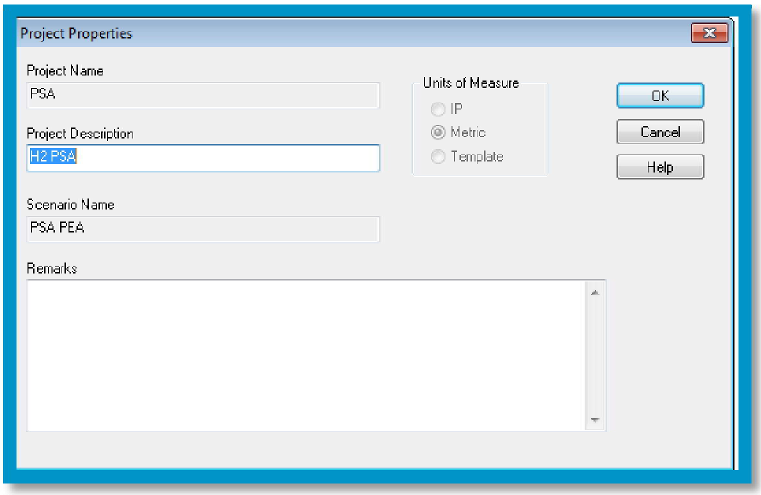



**Fig 5.9: Project Properties Menu**

Second, the inputs under the Unit of Measure Specifications dialog box would appear. This form allows the user to abide or modify with the units of measure that would appear on its domain specification form. Accept the default settings by selecting the option Close on the specification box (Fig 5.10).

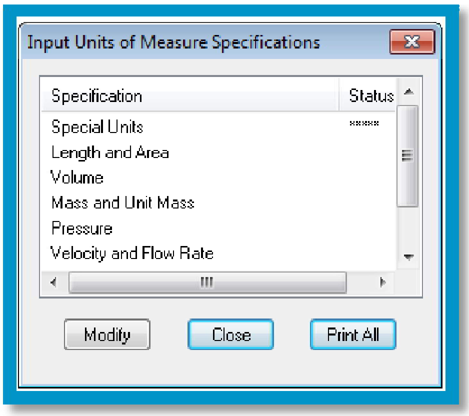



**Fig 5.10: Units of Measure Specification dialog box**

Third, the General Project Data dialog box appears. Since no adjustments of data and currency are needed for this project, click the OK button (Fig 5.11). Note that the currency of the project should remain in Dollar currency only and conversion of the evaluated results can be done based on exact conversion rates.

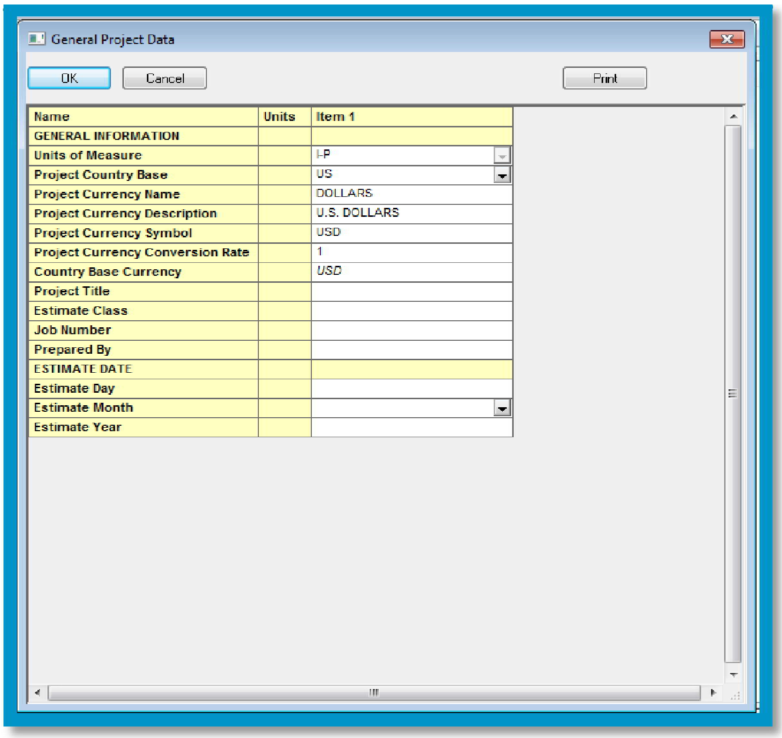



**Fig 5.11: General Project Data Menu**

Fourth, the principal dialogue box "Load Simulator Data?" would exhibit. If yes, select the option Yes to do load the file (Fig 5.12).

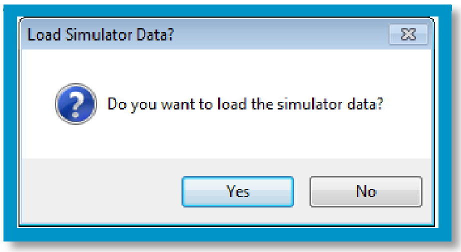



**Fig 5.12: Load Simulator Data dialog box**

Aspen PEA now opens two windows shown below in Fig 5.13. The narrow Project Explorer, on the left, that contains the Process View modes, and an expansive Main Window, at first blank, on the right hand side. When they do not open by themselves, using the View pull-down menu two more windows, Palette and Property, can be opened.

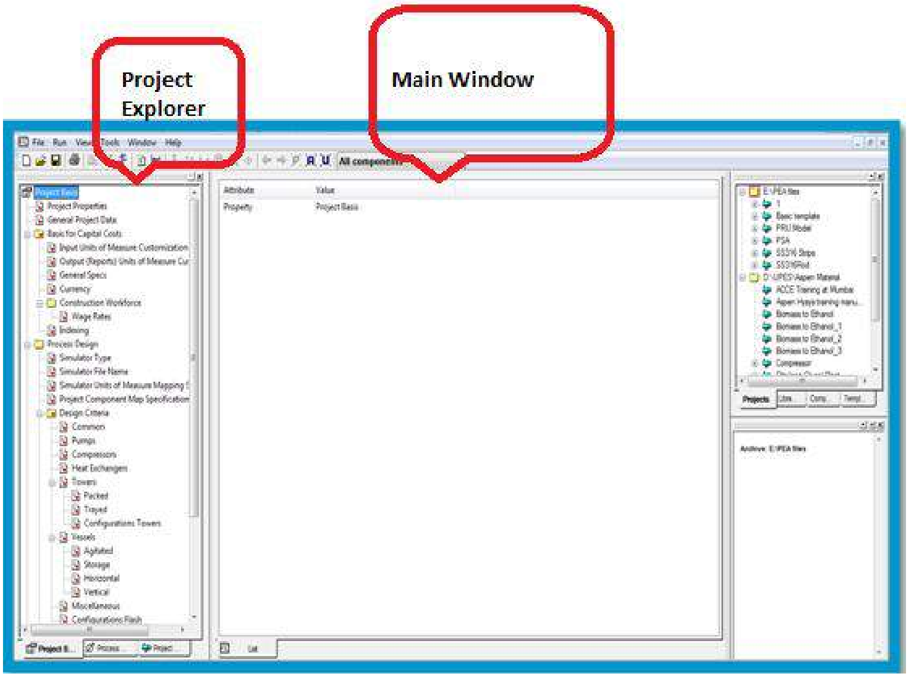
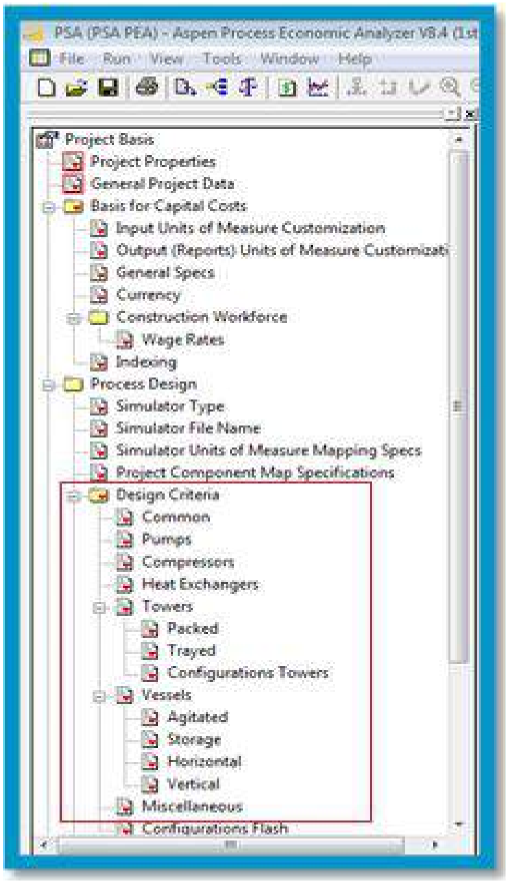
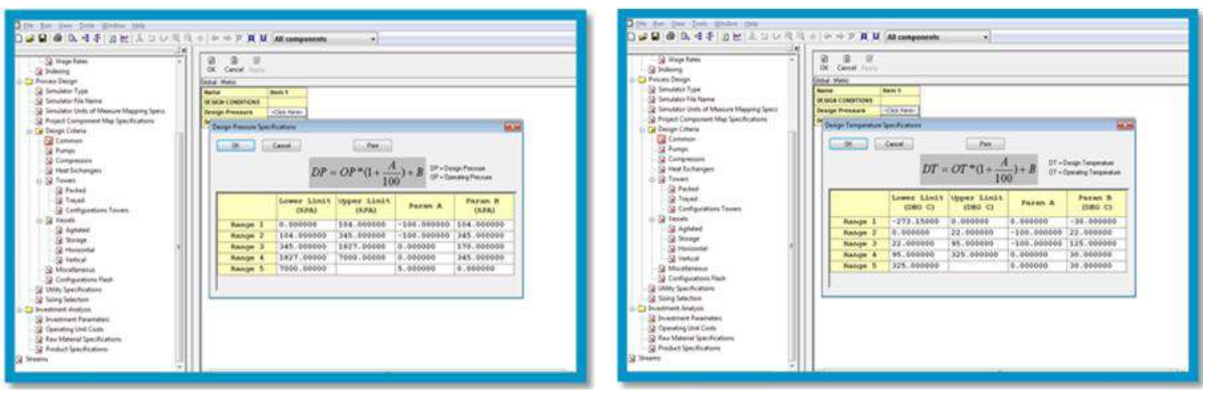



**Fig 5.13: Aspen PEA Project Explorer Menu**

Aspen PEA permits the performer to mention various parameters for equipment sizing or to go with the default values. These are the foundation for equipment set up and for utility description. The primary step in ending this simulation is to scrutinize the project Design Criteria. This could be performed by picking the Project Basis View tab under the Project Explorer menu (Fig 5.14 (a)). It is also to be noted that under the Process Design drop down option, the Design Criteria and Utility Specifications entries would largely be relevant when developing and scrutinizing equipment sizes and costs.




**a. Design Criteria option on Project Basis View**



**b. Design Pressure and Design Temperature specifications**

**Fig 5.14: Project Design Criteria a. Design Criteria option on Project Basis View, b. Design Pressure and Design Temperature specifications**

Under the Design Criteria, default qualities would be available for most sections in the structures. These can be changed relying upon the framework and the parameters, and the mandatory entries need to be entered. Specific attention need to be given to the design temperature and design pressure, during the course of overdesign factors, process vessels residence phase and time, as well as other tower specifications. The performer must be cautious in checking every relevant entry that applies to each of the equipment under evaluation.

The default values associated with the utilities can also be evaluated, if at all in the case of detailed specification. Due to this reason, the Utility Specifications entry should be selected from the Process Design drop down box to generate the Develop Utility Specifications dialog box (Fig 5.15).

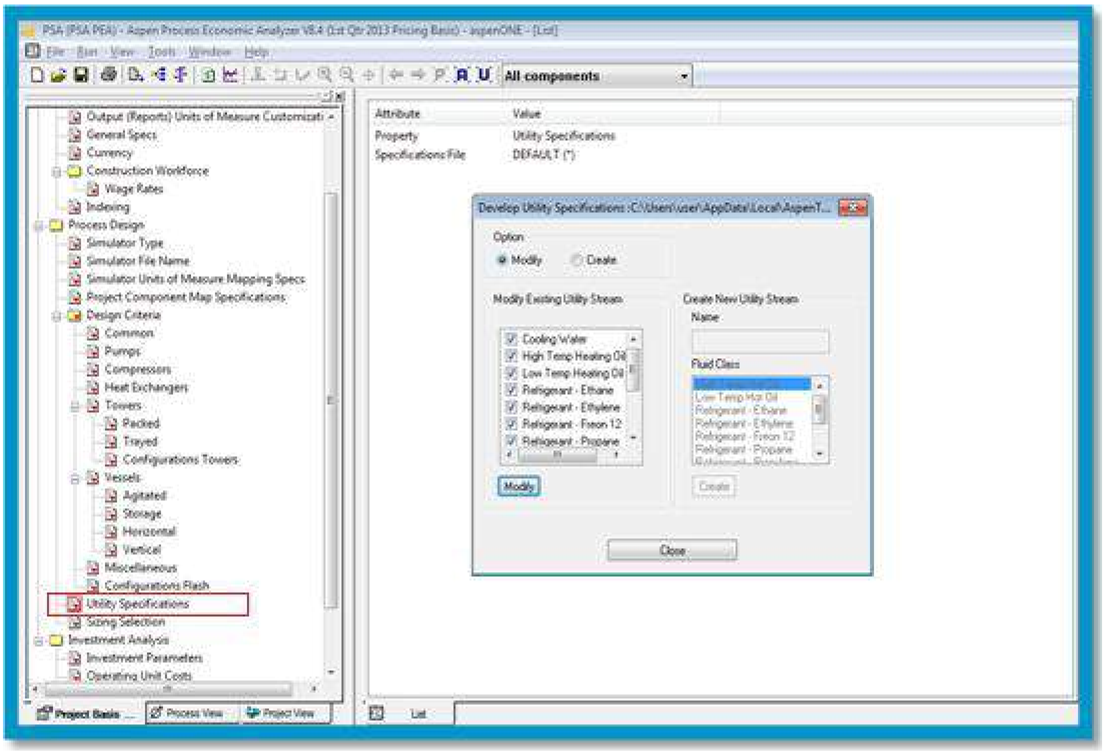



**Fig 5.15: Develop or Modify Utility Specification Menu**

All the available utilities of the project handled by Aspen PEA would be listed. The values that show up as default ought to be scrutinized and changed and insufficient utilities ought to be included request shrewd. Double click on utility stream list entry, whose parameter has to be modified. For example, double click on the Cooling Water entry, as shown in above Fig 5.15 to modify its temperature (Fig 5.16). Left over default values can be modified in a similar way. When the changes are implied, click OK. Also to add additional utility that does not exist in the utility list, on the Develop Utility Specifications dialog box choose the Create option. After creating the new utility, the parameters are entered from the steam table in the Utility specification menu (Smith *et al.*, 2001). When complete, OK button should be selected and this will take the user return to the Develop Utility Specification dialog box.

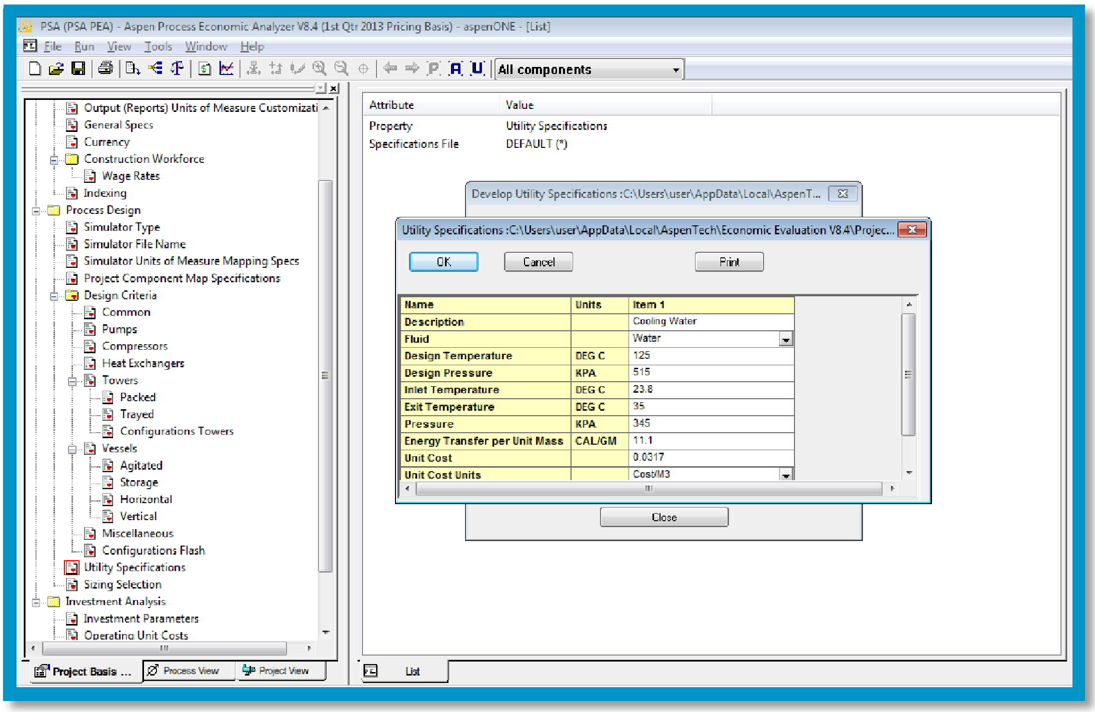


**Fig 5.16: Utility Specification sheet**

Other specifications such as wage rate (Fig 5.17), investment parameter (Fig 5.18), cost index (Fig 5.19) could be modified in the same format explained for the design criteria and utilities.

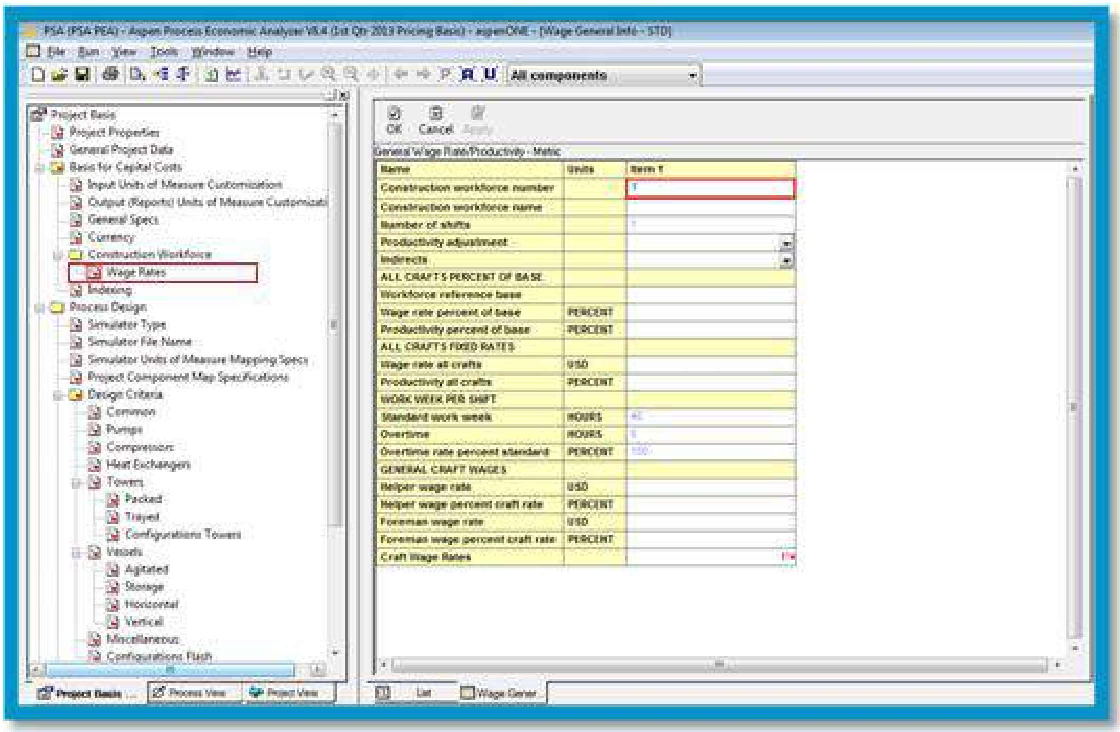


**Fig 5.17: General Wage Rate sheet**

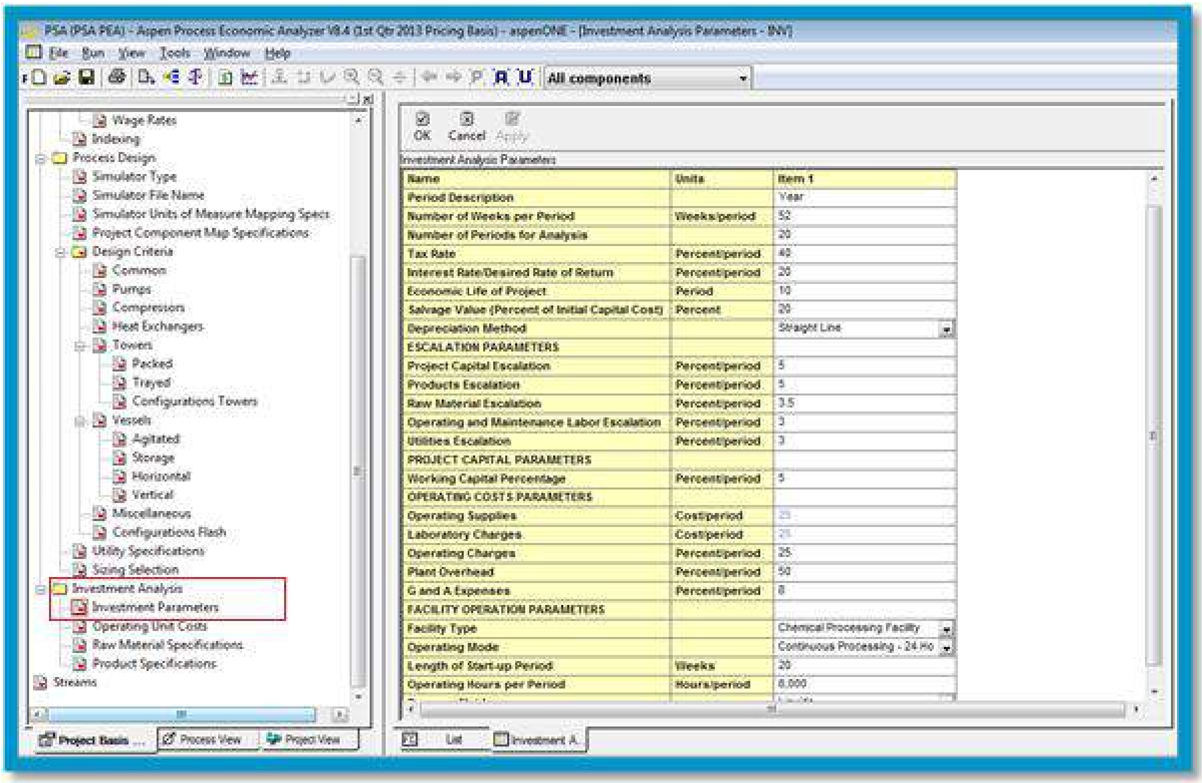



**Fig 5.18: Investment Analysis Parameters**

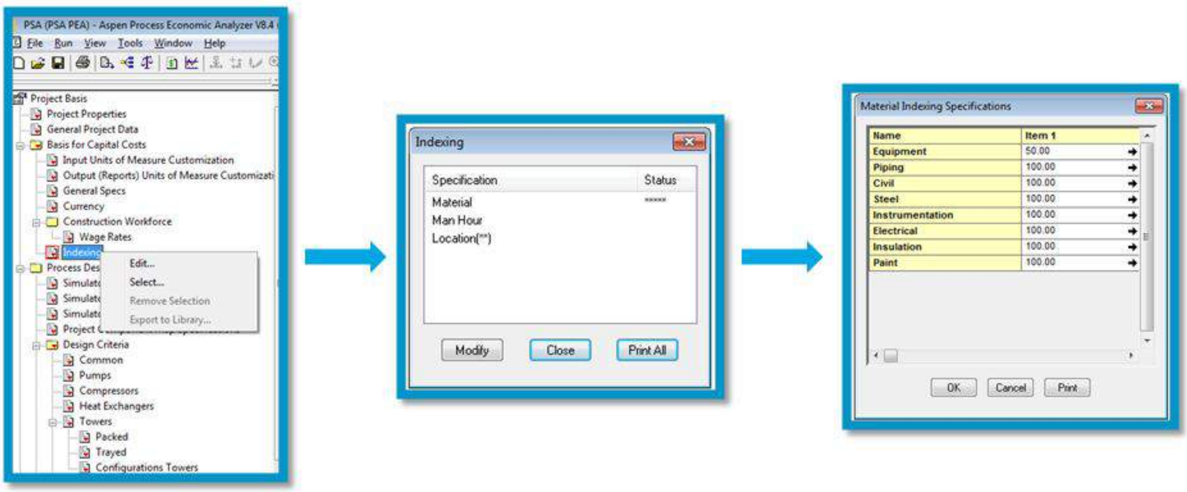



**Fig 5.19: Stages to enter Material Index Specification**

## 5.1.1 Mapping Process of Simulation Units into Aspen PEA:

After the set up was completed initially, the subsequent step would be to map the process simulation unit that is blocks, suites or subroutines into further elaborate set up of process equipment and related plant bulks, that covers the installation items, such as piping, instrumentation, insulation, paint, etc. To begin the mapping step in the Aspen PEA, on the

Process View section of the Project Explorer box, each equipment is right-clicked and when Map option was selected, the below dialog box of Mapping will appear (Fig 5.20).

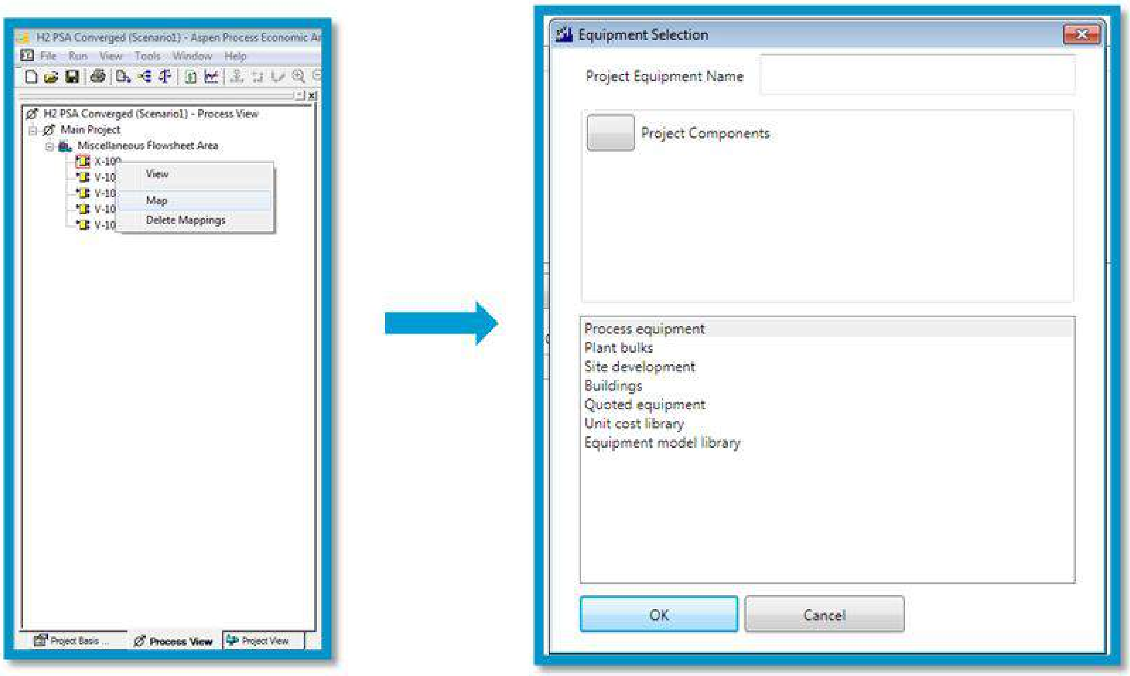



**Fig 5.20: Mapping process for Simulator items**

For the PSA unit, every entity should be mapped and sized sequentially, as the Project Components options are assessed and checked in from yellow to green option, as shown in Fig 5.21. When this key is not checked in to green, this would indicate that only the mapping step was dealt to complete. While those indications are checked to green, apart from mapping it will also generate the equipment sizing and evaluation form section. When there are numerous process units of a particular kind, it is favorable to map every process unit individually.

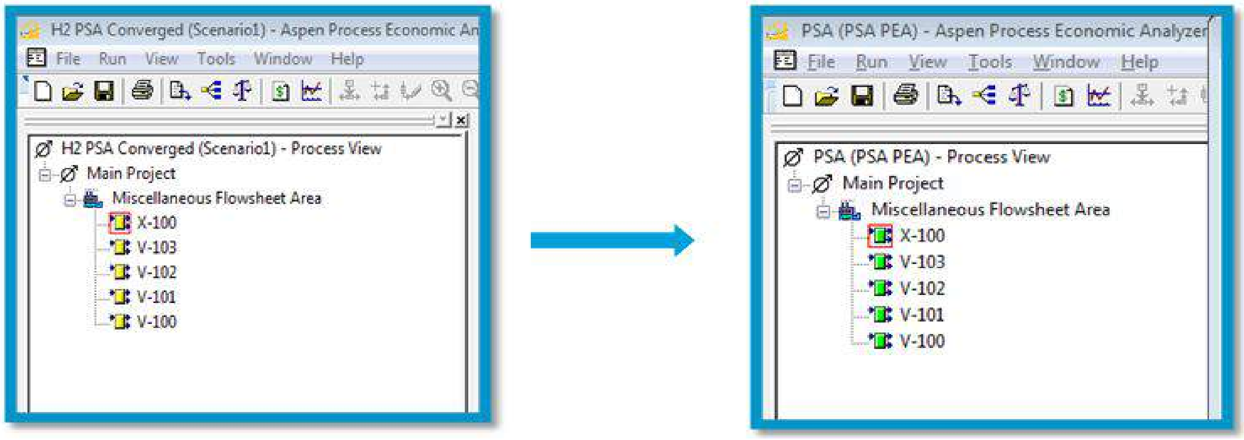



**Fig 5.21: Validation check-in indication for Mapped equipments**

In this case, the mapping procedure was carried out as follows:

X-100 (Column):

i. When the Map option was selected, the dialog box appeared as shown in Fig 5.20.

ii. The selection stages for X-100 were: Process Equipment -> Towers, columns-trayed/packed -> Tower-single diameter -> Packed tower. (Fig 5.22)

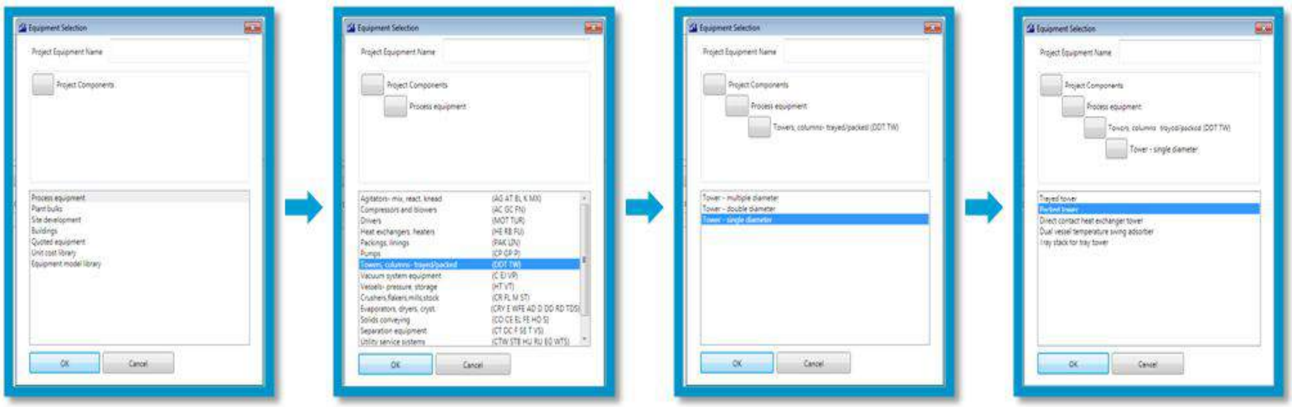


**Fig 5.22: Mapping process for X-100-Adsorption Column**

V-103 (Tail-Gas Storage Tank):

i. The selection stages for V-103 were: Process Equipment -> Vessel-pressure, storage -> Vessel-vertical tank. (Fig 5.23)

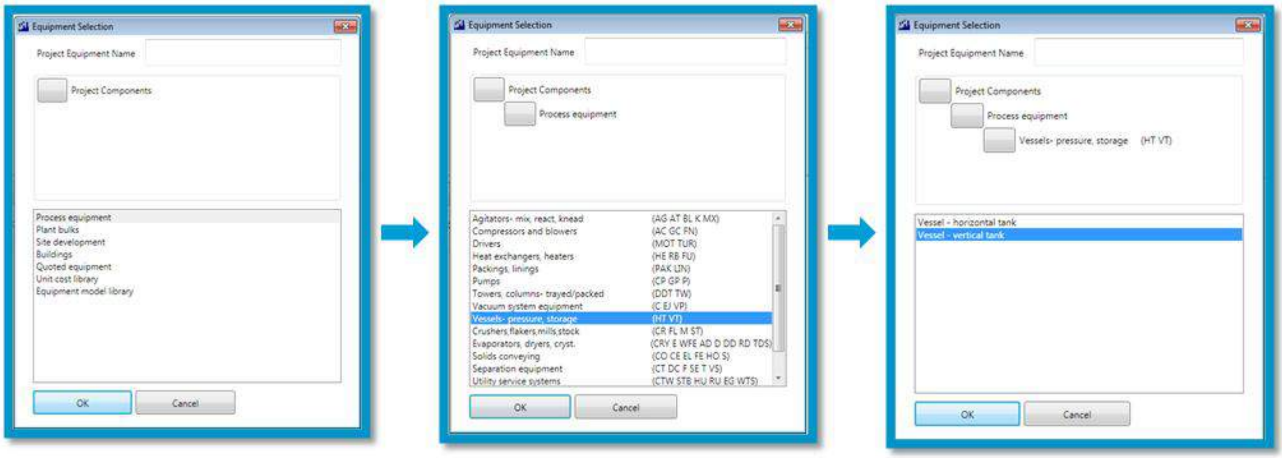



**Fig 5.23: Mapping process for V-103-Tail Gas Storage Tank**

V-102 (Tail-Gas Demister):

i. The selection stages for V-102 were: Process Equipment -> Separation Equipment -> Centrifuge. (Fig 5.24)

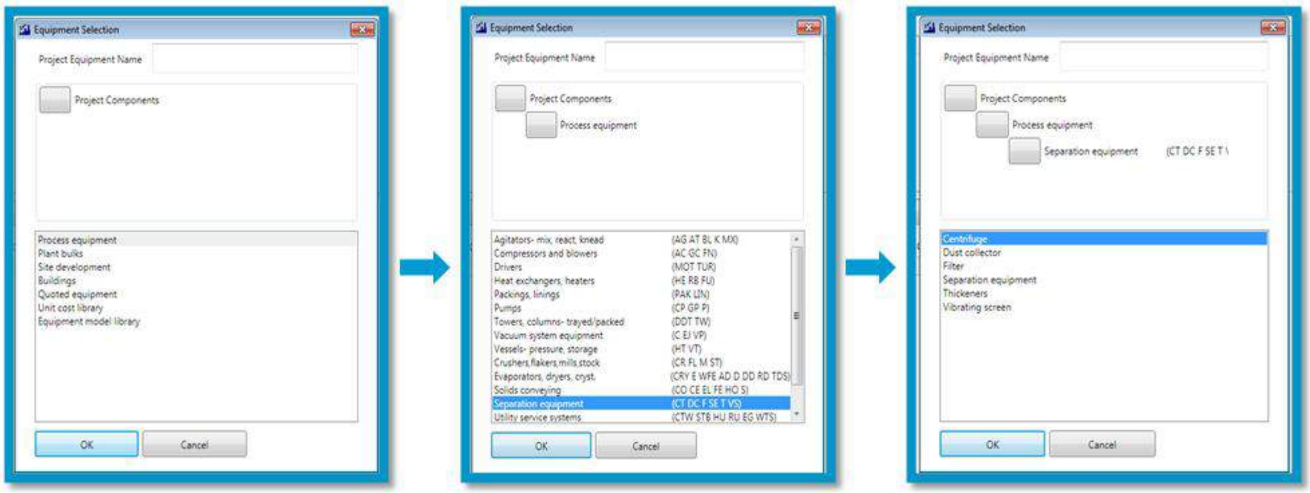



**Fig 5.24: Mapping process for V-102-Tail Gas Demister**

V-100 (Product Storage Tank):

i. The selection stages for V-100 were: Process Equipment -> Vessel- pressure, storage -> Vessel-vertical tank. (Fig 5.25)

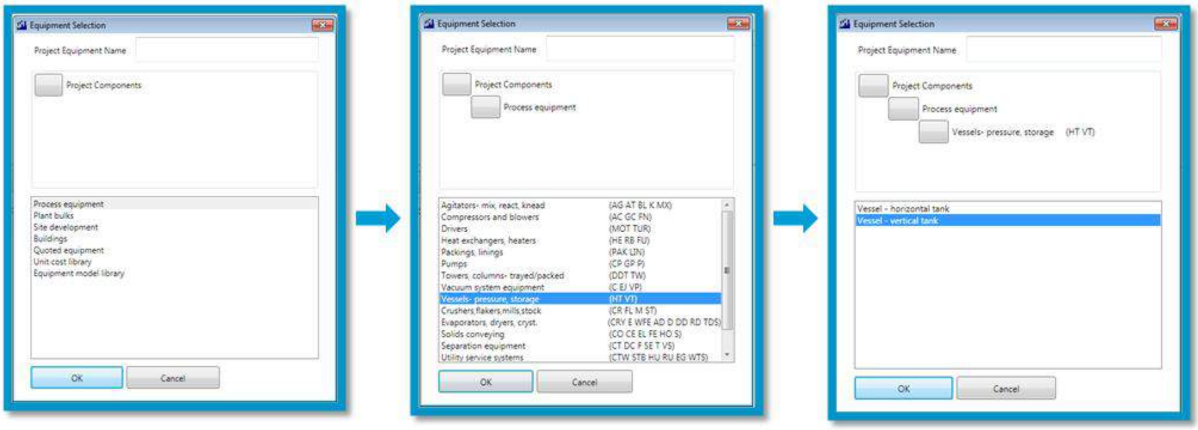


**Fig 5.25: Mapping process for V-100-Product Storage Tank**

V-101 (Product Demister):

i. The selection stages for V-102 were: Process Equipment -> Separation Equipment -> Centrifuge. (Fig 5.26)

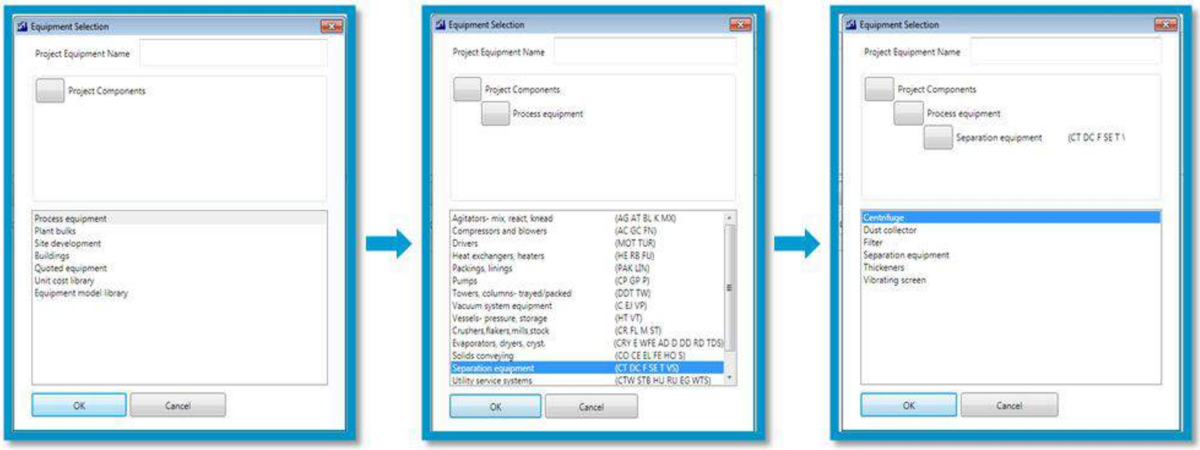


**Fig 5.26: Mapping process for V-100-Product Demister**

At this point, when all the equipments have been checked-in through mapping, the equipment items had been sized by Aspen PEA, of whose mapping evaluations are relied upon the simulator parameters, and also the default entries specified prior. Since every equipment entity was sized, it appeared in the Aspen PEA Main window in list format, which is termed as the List Window (Fig 5.27). The List tab beneath the Main window indicates that the equipment entities were listed under the Workbook Mode and the boxes appeared in blue to the left of each item in the list denoted the Project Components.

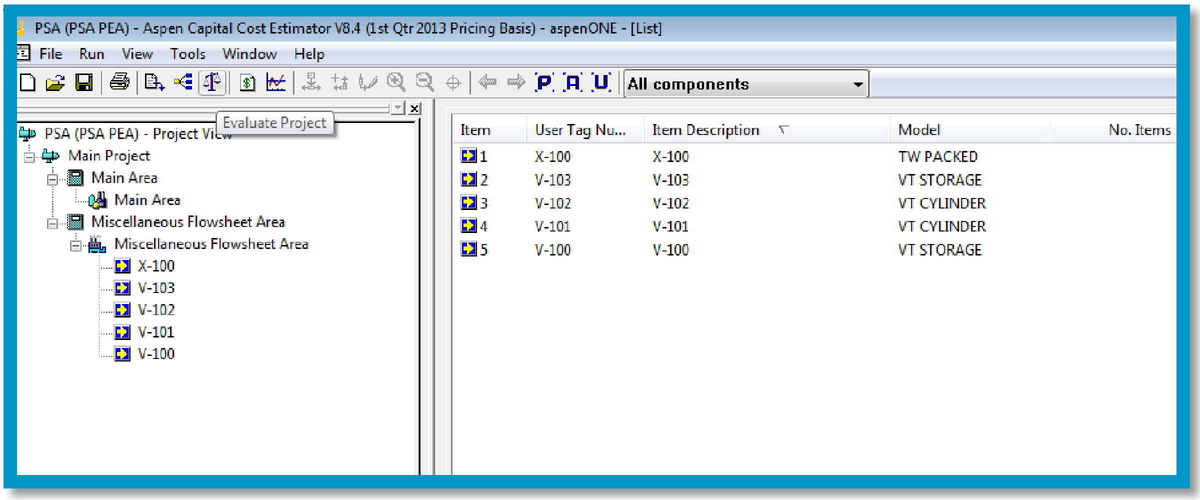



**Fig 5.27: List Window of Aspen PEA (Project View Section)**

## 5.1.2 Equipment Sizing Step:

In the List Window, when the status of the Project Components appear to be question mark '?', then the equipment sizing step should be proceeded.

It is viable to open and generate the Aspen PEA Process Flow Diagram, using the View option from the dropdown menu under which Process Flow Diagram selection would appear (Fig 5.28). Also, the Aspen PEA generates the Block Flow Diagram indicates the simulation flowsheet, that would also be displayed under the View dropdown menu (Fig 5.29). Select the Stream list option under View dropdown, to view the stream details and parameters on Aspen PEA (Fig 5.30).

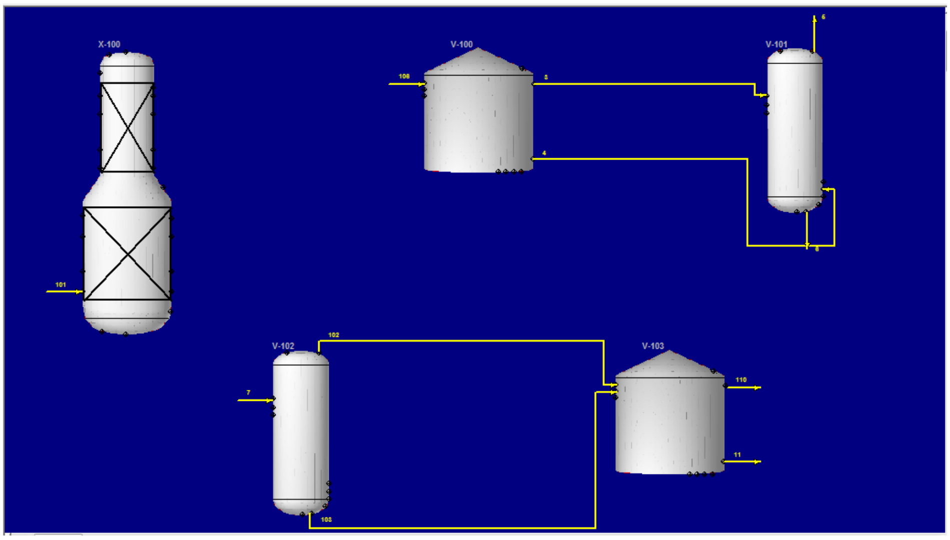



**Fig 5.28: Process Flow Diagram of PSA generated from Aspen PEA**

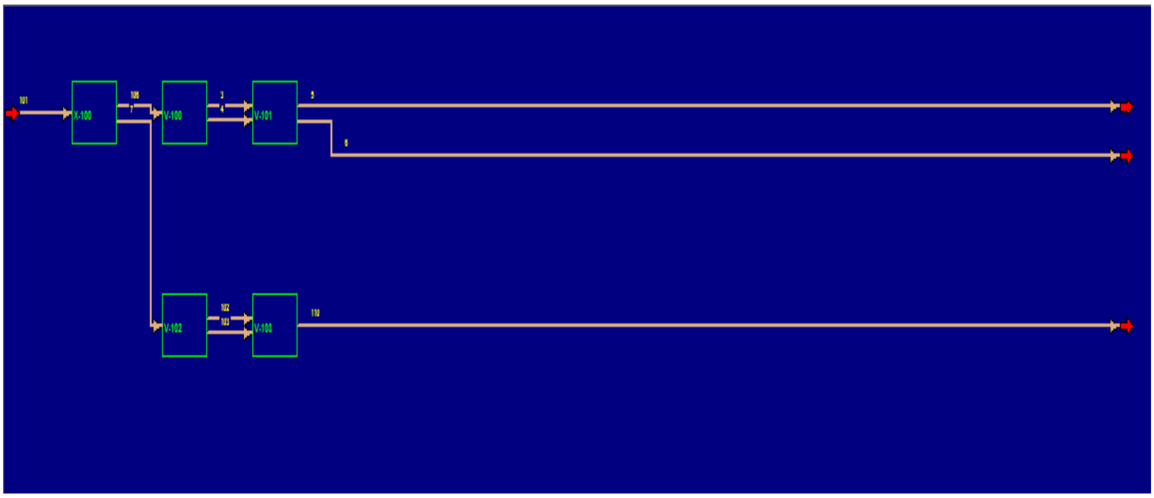


**Fig 5.29: Block Flow Diagram of PSA generated from Aspen PEA**

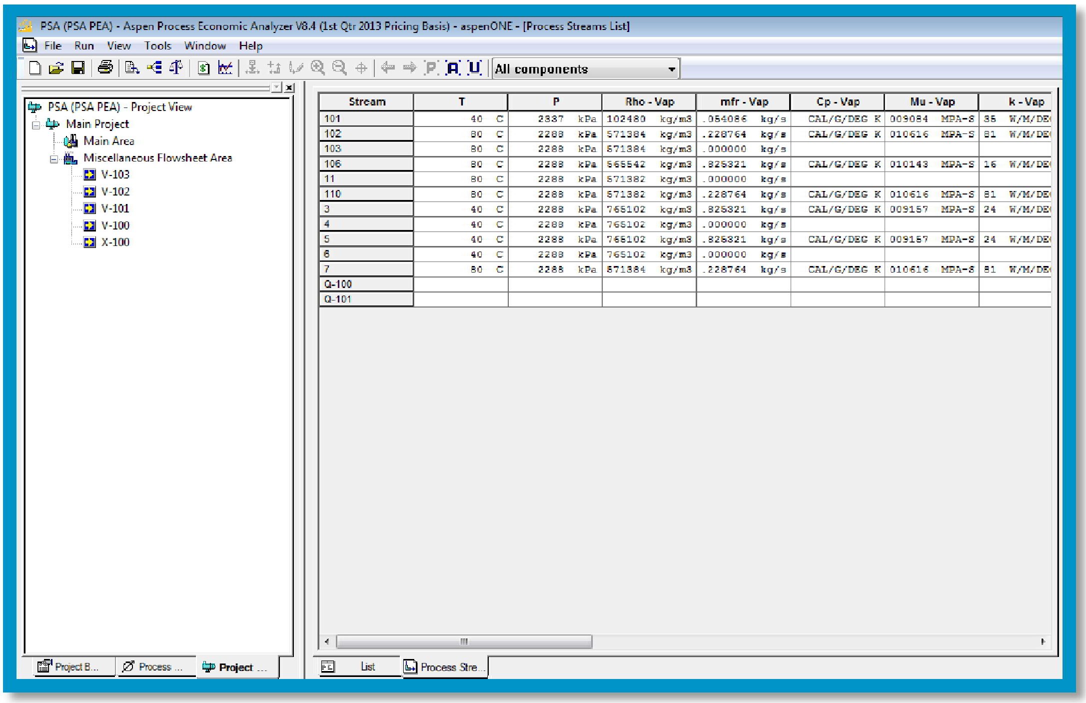



**Fig 5.30: Stream List of the Simulator in Aspen PEA**

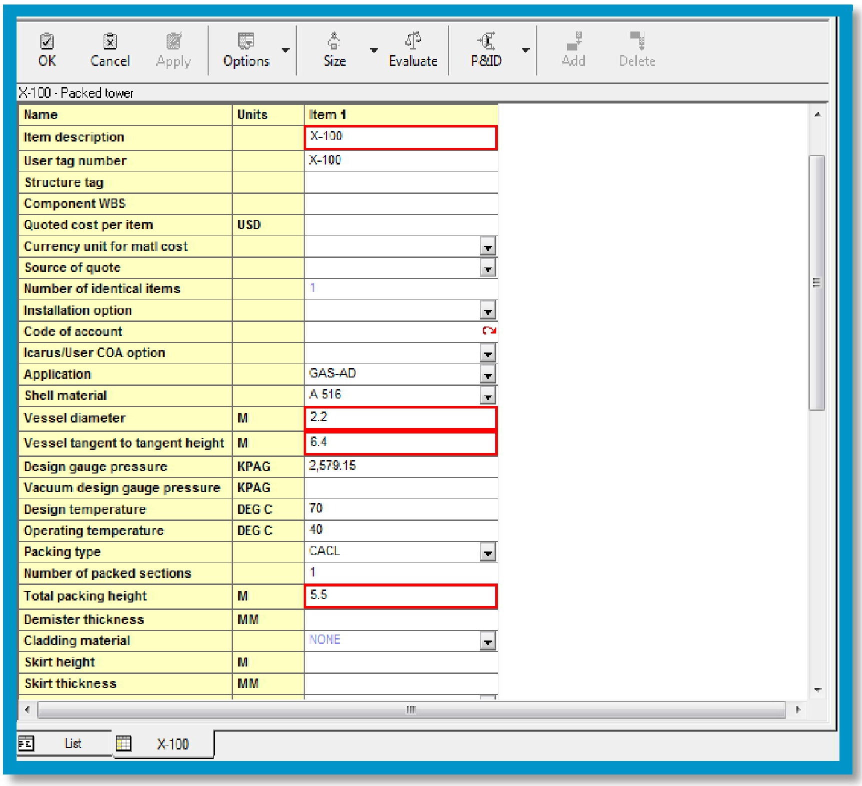
To view each of the component specification form of the model, use the double click on the entities under the Aspen PEA Workbook window, else use the symbol in the Process Flow Diagram. The basic process conditions of that equipment selected (such as design pressure, design temperature, operating temperature, shell material and other mandatory data, Table 4.1) has to be entered in this specification form.

Observe that the Adsorption Column X-100 (Fig 5.31) was designed by Aspen PEA to have diameter of 2.2m and a 6.4m height (tangent-to-tangent) for Gas-Adsorption packed column.

The base material of the column was A516 Grade 70 (Composition given below in Table 5.1). During the initial evaluation, the column was evaluated without packing with single split. The column was also evaluated for multi-diameter packing type, which was opted during the mapping stage.

**Table 5.1: Chemical Composition of A516-Grade 70**

| TYPICAL CHEMICAL COMPOSITION OF ASTM A516 GRADE 70 | |
|---|---|
| Composition | Percentage |
| C | 0.10/0.22 |
| Si | 0.6 |
| Mn | 1/1.17 |
| P | 0.03 |
| S | 0.03 |
| Al | 0.02 |
| Cr | 0.3 |



OK Cancel Apply Options Size Evaluate P&ID Add Delete

X-100 - Packed tower

| Name | Units | Item 1 |
|---|---|---|
| Item description | | X-100 |
| User tag number | | X-100 |
| Structure tag | | |
| Component WBS | | |
| Quoted cost per item | USD | |
| Currency unit for matl cost | | |
| Source of quote | | |
| Number of identical items | | 1 |
| Installation option | | |
| Code of account | | |
| Icarus/User COA option | | |
| Application | | GAS-AD |
| Shell material | | A 516 |
| Vessel diameter | M | 2.2 |
| Vessel tangent to tangent height | M | 6.4 |
| Design gauge pressure | KPAG | 2,579.15 |
| Vacuum design gauge pressure | KPAG | |
| Design temperature | DEG C | 70 |
| Operating temperature | DEG C | 40 |
| Packing type | | CACL |
| Number of packed sections | | 1 |
| Total packing height | M | 5.5 |
| Demister thickness | MM | |
| Cladding material | | NONE |
| Skirt height | M | |
| Skirt thickness | MM | |

List X-100

**Fig 5.31: X-100-Adsorption column sizing specification sheet**

Through this specification form, P&ID of each equipment can be acquired (Fig 5.32). This option was useful in checking, addition or removal of the connecting instruments. Under the Options selection (Fig 5.33), the Pipe Item Details (P) (Fig 5.34), Instrumentation (P) (Fig 5.35) and Nozzle (Fig 5.36) specification, addition or removal can be carried out.

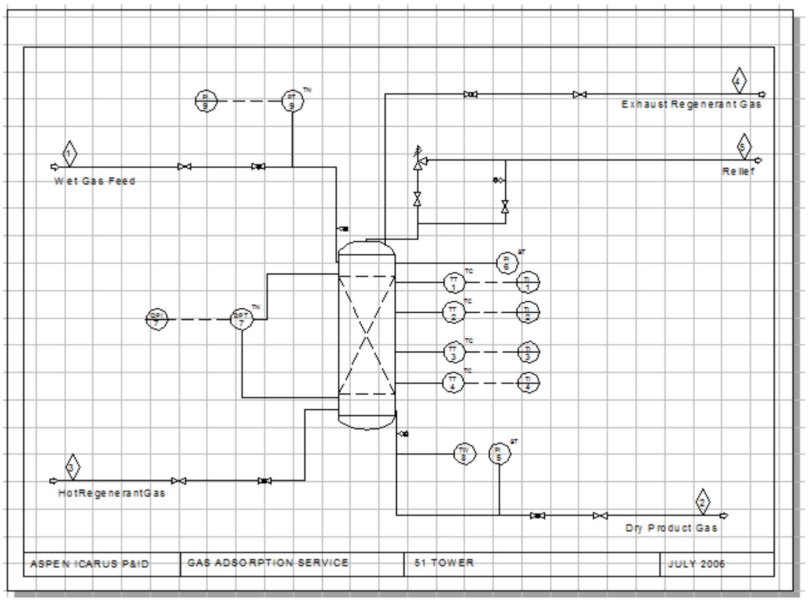



**Fig 5.32: P&ID of X-100-Adsorption column generated from Aspen PEA**

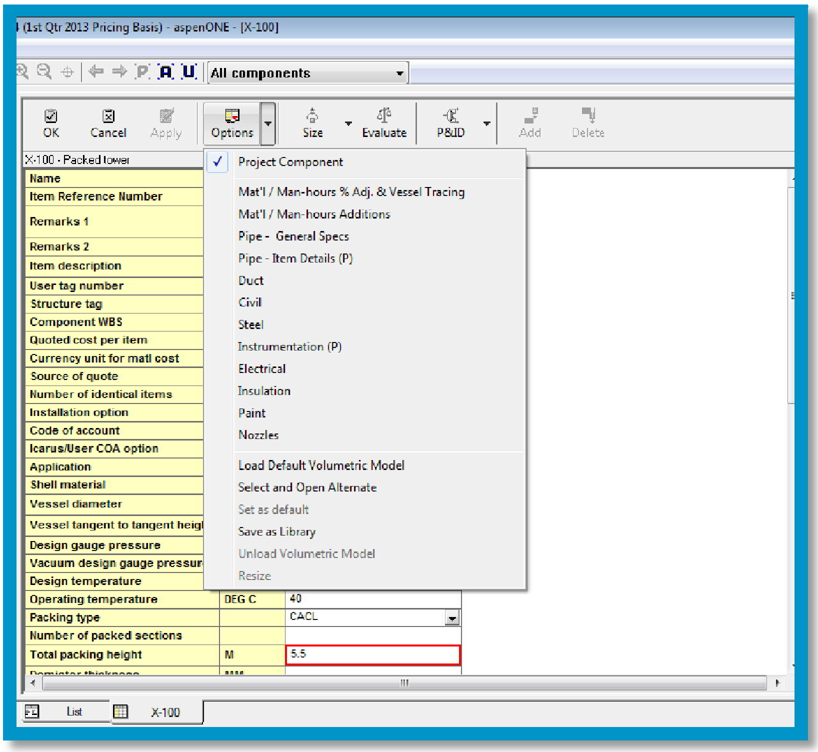



**Fig 5.33: Options selection for detail specification**

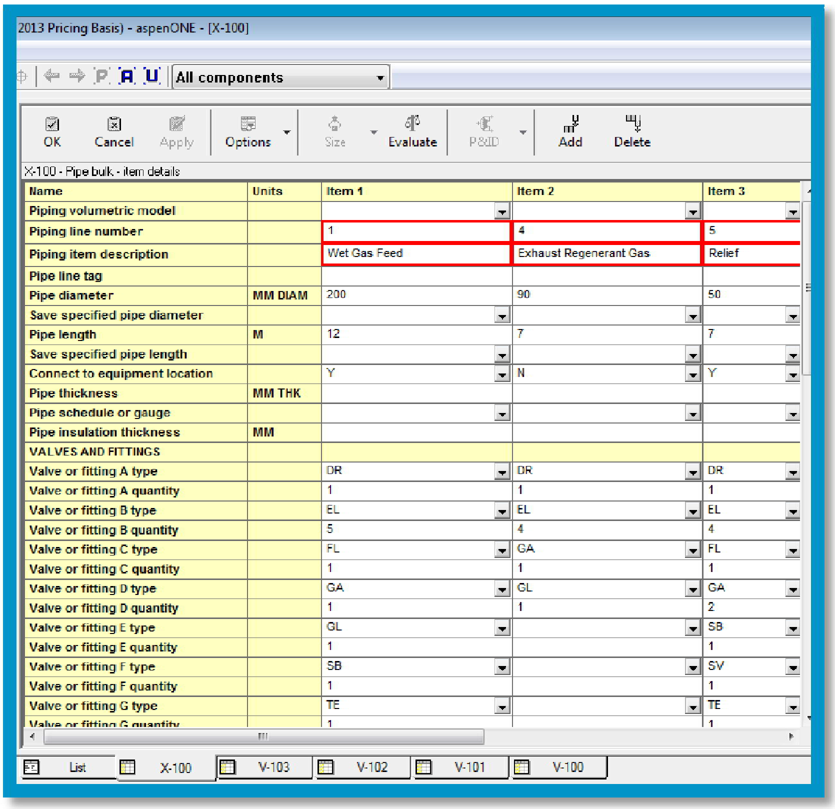



**Fig 5.34: Pipe Item Details**

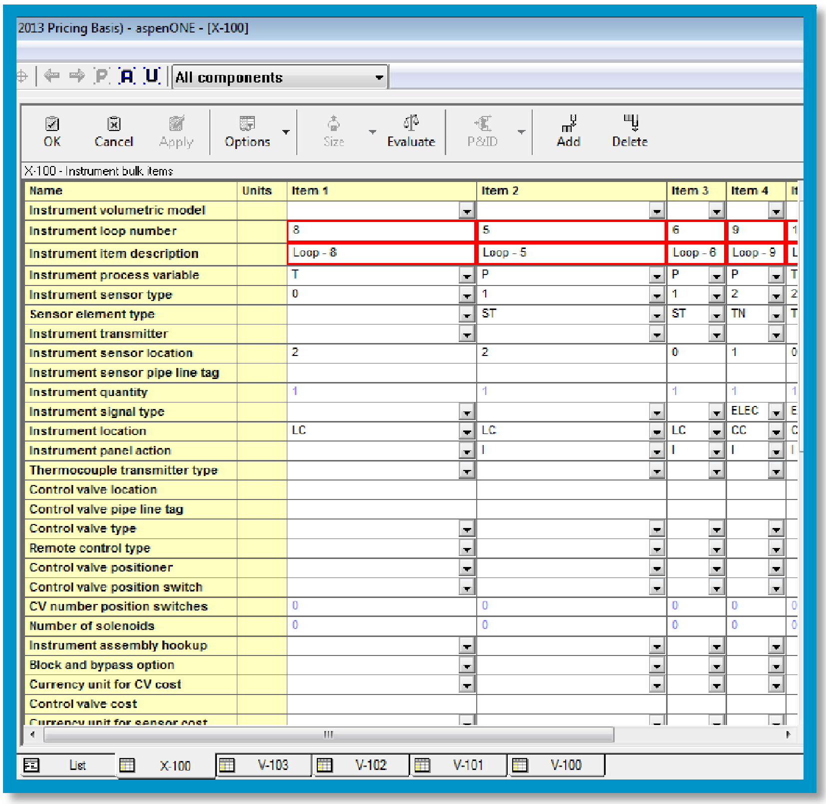


**Fig 5.35: P&ID Instrumentation list**

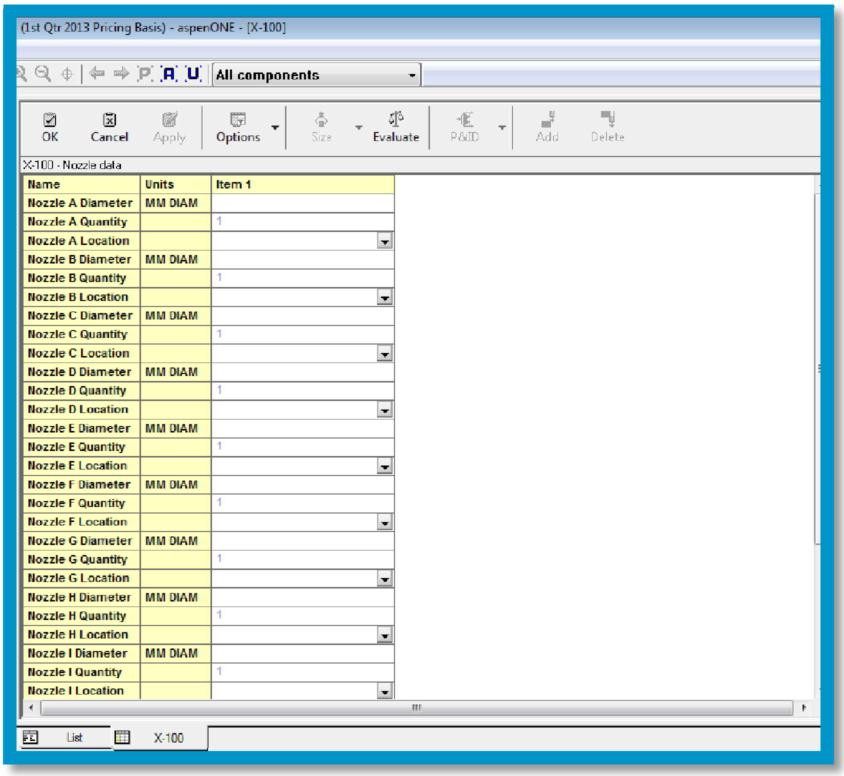


**Fig 5.36: Nozzle list**

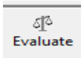
Similar procedure was followed for filling up the component specification form of all the other process equipments. Modifications can be implied to every equipment sizes generated by Aspen PEA or to the default values used by Aspen PEA. (It is to be noted down that the default values would be displayed as blue font color). As modifications are put forth, reliable results are regulated by Aspen PEA.

**Table 5.2: Chemical Composition of A106-Grade B**

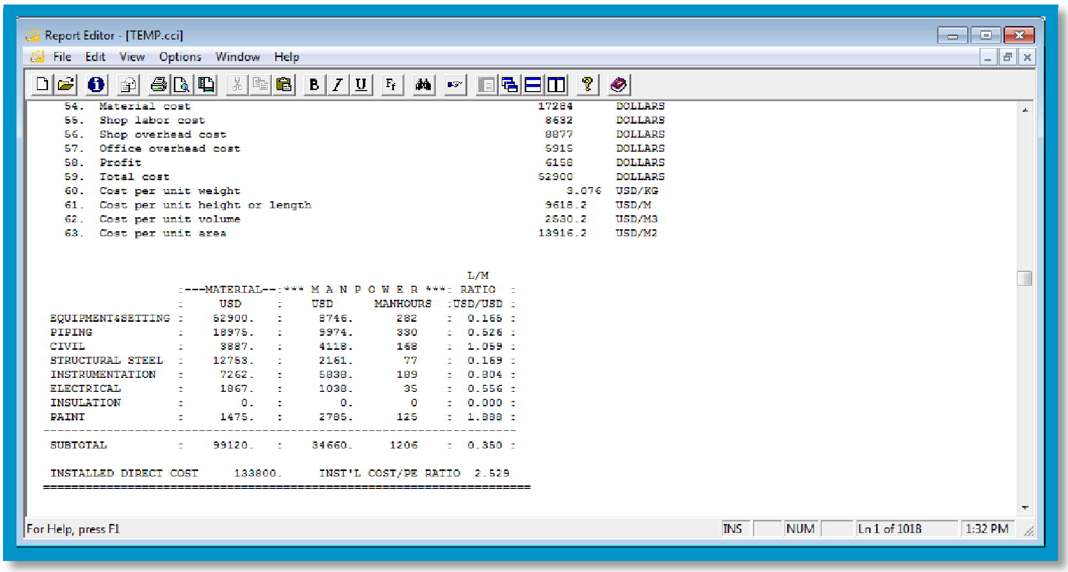
| CHEMICAL COMPOSITION OF A106 GRADE B | |
|---|---|
| **Composition** | **Percentage** |
| C | 0.3 |
| Mn | 0.29-1.06 |
| P | 0.035 |
| S | 0.1 |
| Si | 0.4 |
| Cu | 0.4 |
| Mo | 0.15 |
| Ni | 0.4 |
| V | 0.08 |

**Table 5.3: Chemical Composition of A235-Grade WPB**

| CHEMICAL COMPOSITION OF A235 WPB GRADE | |
|---|---|
| **Composition** | **Percentage** |
| C | 0.3 |
| Mn | 0.29-1.06 |
| P | 0.05 |
| S | 0.058 |
| Si | 0.1 (min.) |
| Cu | 0.4 |
| Mo | 0.15 |
| Ni | 0.4 |
| V | 0.08 |

Detailed evaluation report of process equipments can be generated individually in two methods. First way is to right click on the equipment entities under the Process Flow Diagram and click on the Evaluate 

option in the menu that would be available. Alternatively, on every component specification form sheet of the entities, click the Evaluate option (Fig 5.31). These steps produce the economic evaluation report of all the process equipments individually. It is to be mentioned here that only a small portion of the Evaluation report is shown in Fig 5.37.



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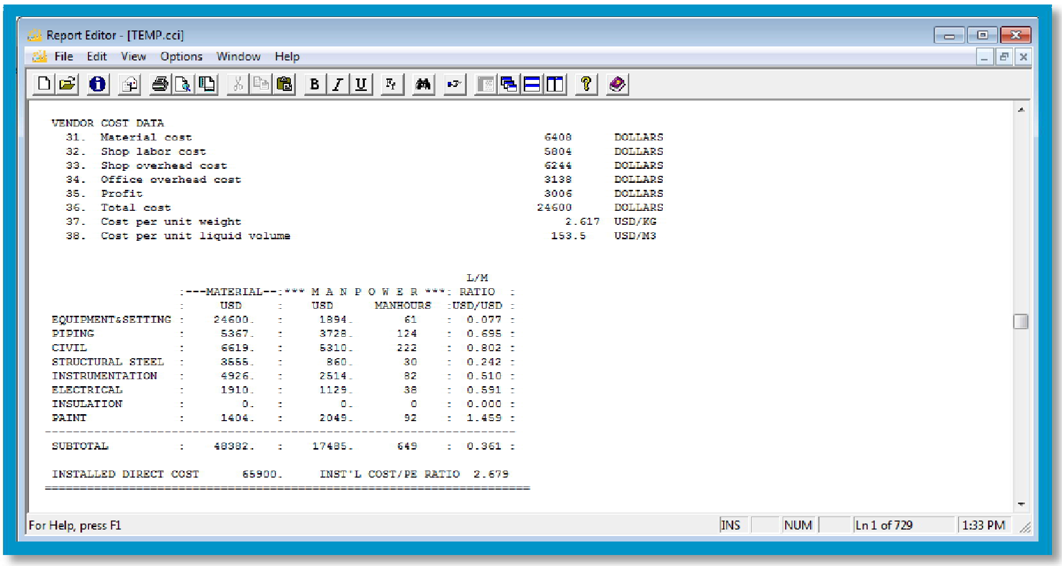
| | | | |
|---|---|---|---|
| 54. | Material cost | 17284 | DOLLARS |
| 55. | Shop labor cost | 8632 | DOLLARS |
| 56. | Shop overhead cost | 8877 | DOLLARS |
| 57. | Office overhead cost | 5915 | DOLLARS |
| 58. | Profit | 6158 | DOLLARS |
| 59. | Total cost | 52900 | DOLLARS |
| 60. | Cost per unit weight | 3.076 | USD/KG |
| 61. | Cost per unit height or length | 9618.2 | USD/M |
| 62. | Cost per unit volume | 2530.2 | USD/M3 |
| 63. | Cost per unit area | 13916.2 | USD/M2 |

| | ---MATERIAL--- | *** M A N P O W E R *** | | L/M RATIO |
|---|---|---|---|---|
| | USD | USD | MANHOURS | USD/USD |
| EQUIPMENT&SETTING | 52900. | 8746. | 282 | 0.165 |
| PIPING | 18975. | 9974. | 330 | 0.526 |
| CIVIL | 3887. | 4118. | 168 | 1.059 |
| STRUCTURAL STEEL | 12753. | 2161. | 77 | 0.169 |
| INSTRUMENTATION | 7262. | 5838. | 189 | 0.804 |
| ELECTRICAL | 1867. | 1038. | 35 | 0.556 |
| INSULATION | 0. | 0. | 0 | 0.000 |
| PAINT | 1475. | 2785. | 125 | 1.888 |
| SUBTOTAL | 99120. | 34660. | 1206 | 0.350 |

INSTALLED DIRECT COST 133800. INST'L COST/PE RATIO 2.529

For Help, press F1

Fig 5.37: Economic Evaluation report of X-100-Adsorption Column



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VENDOR COST DATA

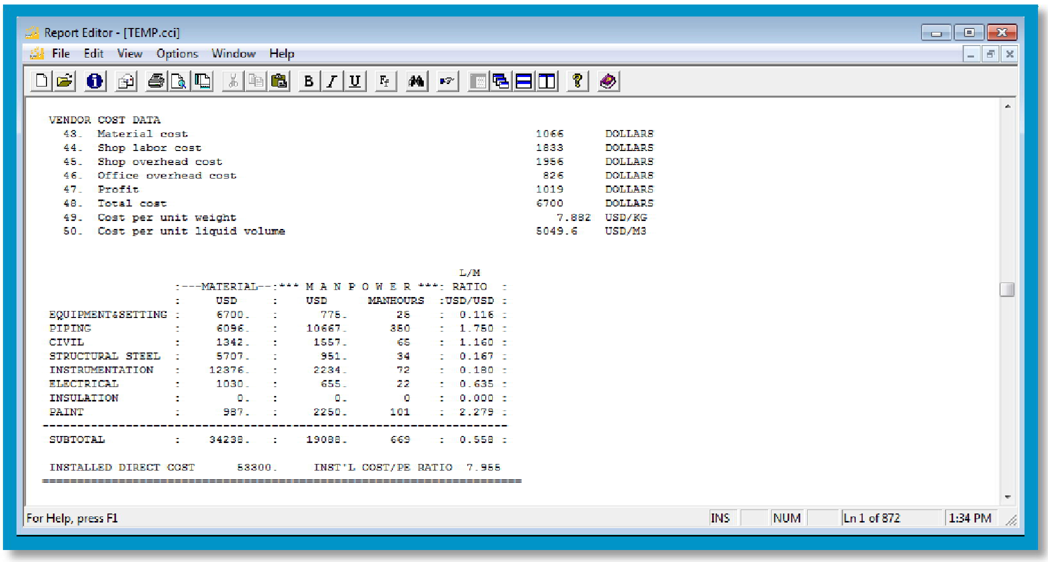
| | | | |
|---|---|---|---|
| 31. | Material cost | 6408 | DOLLARS |
| 32. | Shop labor cost | 5804 | DOLLARS |
| 33. | Shop overhead cost | 6244 | DOLLARS |
| 34. | Office overhead cost | 3138 | DOLLARS |
| 35. | Profit | 3006 | DOLLARS |
| 36. | Total cost | 24600 | DOLLARS |
| 37. | Cost per unit weight | 2.617 | USD/KG |
| 38. | Cost per unit liquid volume | 153.5 | USD/M3 |

| | ---MATERIAL--- | *** M A N P O W E R *** | | L/M RATIO |
|---|---|---|---|---|
| | USD | USD | MANHOURS | USD/USD |
| EQUIPMENT&SETTING | 24600. | 1894. | 61 | 0.077 |
| PIPING | 5367. | 3728. | 124 | 0.695 |
| CIVIL | 6619. | 5310. | 222 | 0.802 |
| STRUCTURAL STEEL | 3555. | 860. | 30 | 0.242 |
| INSTRUMENTATION | 4926. | 2514. | 82 | 0.510 |
| ELECTRICAL | 1910. | 1129. | 38 | 0.591 |
| INSULATION | 0. | 0. | 0 | 0.000 |
| PAINT | 1404. | 2049. | 92 | 1.459 |
| SUBTOTAL | 48382. | 17485. | 649 | 0.361 |

INSTALLED DIRECT COST 65900. INST'L COST/PE RATIO 2.679

For Help, press F1

Fig 5.38: Economic Evaluation report of V-100-Product Storage Tank



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VENDOR COST DATA

| | | | |
|---|---|---|---|
| 43. | Material cost | 1066 | DOLLARS |
| 44. | Shop labor cost | 1833 | DOLLARS |
| 45. | Shop overhead cost | 1956 | DOLLARS |
| 46. | Office overhead cost | 826 | DOLLARS |
| 47. | Profit | 1019 | DOLLARS |
| 48. | Total cost | 6700 | DOLLARS |
| 49. | Cost per unit weight | 7.882 | USD/KG |
| 50. | Cost per unit liquid volume | 5049.6 | USD/M3 |

| | MATERIAL | MANPOWER | | L/M RATIO |
|---|---|---|---|---|
| | USD | USD | MANHOURS | USD/USD |
| EQUIPMENT&SETTING | 6700. | 775. | 25 | 0.116 |
| PIPING | 6096. | 10667. | 350 | 1.750 |
| CIVIL | 1342. | 1557. | 65 | 1.160 |
| STRUCTURAL STEEL | 5707. | 951. | 34 | 0.167 |
| INSTRUMENTATION | 12376. | 2234. | 72 | 0.180 |
| ELECTRICAL | 1030. | 655. | 22 | 0.635 |
| INSULATION | 0. | 0. | 0 | 0.000 |
| PAINT | 987. | 2250. | 101 | 2.279 |
| SUBTOTAL | 34238. | 19088. | 669 | 0.558 |

INSTALLED DIRECT COST 53300. INST'L COST/PE RATIO 7.955

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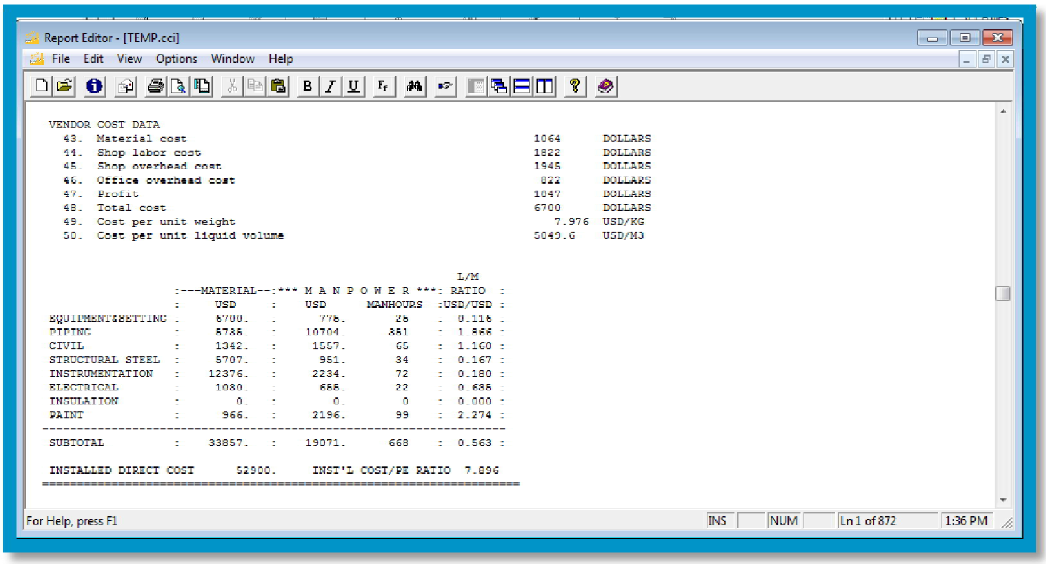
**Fig 5.39: Economic Evaluation report of V-101-Product Demister**



Report Editor - [TEMP.cci]

VENDOR COST DATA

| | | | |
|---|---|---|---|
| 43. | Material cost | 1064 | DOLLARS |
| 44. | Shop labor cost | 1822 | DOLLARS |
| 45. | Shop overhead cost | 1945 | DOLLARS |
| 46. | Office overhead cost | 822 | DOLLARS |
| 47. | Profit | 1047 | DOLLARS |
| 48. | Total cost | 6700 | DOLLARS |
| 49. | Cost per unit weight | 7.976 | USD/KG |
| 50. | Cost per unit liquid volume | 5049.6 | USD/M3 |

| | MATERIAL | MANPOWER | | L/M RATIO |
|---|---|---|---|---|
| | USD | USD | MANHOURS | USD/USD |
| EQUIPMENT&SETTING | 6700. | 775. | 25 | 0.116 |
| PIPING | 5735. | 10704. | 351 | 1.866 |
| CIVIL | 1342. | 1557. | 65 | 1.160 |
| STRUCTURAL STEEL | 5707. | 951. | 34 | 0.167 |
| INSTRUMENTATION | 12376. | 2234. | 72 | 0.180 |
| ELECTRICAL | 1030. | 655. | 22 | 0.635 |
| INSULATION | 0. | 0. | 0 | 0.000 |
| PAINT | 966. | 2196. | 99 | 2.274 |
| SUBTOTAL | 33857. | 19071. | 668 | 0.563 |

INSTALLED DIRECT COST 52900. INST'L COST/PE RATIO 7.896

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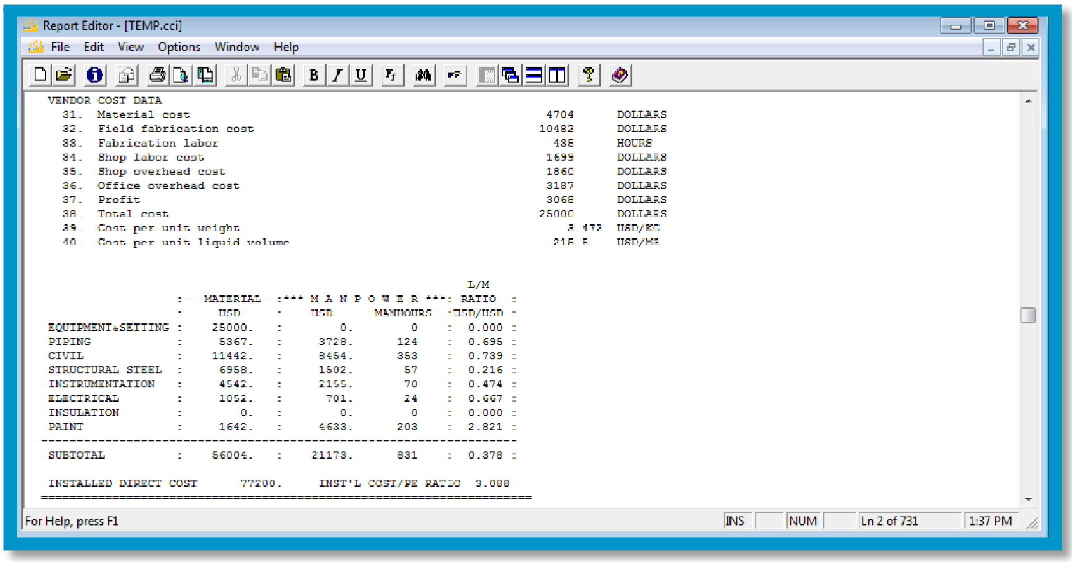
**Fig 5.40: Economic Evaluation report of V-102-Tail Gas Demister**



VENDOR COST DATA

| | | | |
|---|---|---|---|
| 31. | Material cost | 4704 | DOLLARS |
| 32. | Field fabrication cost | 10482 | DOLLARS |
| 33. | Fabrication labor | 435 | HOURS |
| 34. | Shop labor cost | 1699 | DOLLARS |
| 35. | Shop overhead cost | 1860 | DOLLARS |
| 36. | Office overhead cost | 3187 | DOLLARS |
| 37. | Profit | 3068 | DOLLARS |
| 38. | Total cost | 25000 | DOLLARS |
| 39. | Cost per unit weight | 3.472 | USD/KG |
| 40. | Cost per unit liquid volume | 215.5 | USD/M3 |

| | MATERIAL | MANPOWER | | L/M RATIO |
|---|---|---|---|---|
| | USD | USD | MANHOURS | USD/USD |
| EQUIPMENT&SETTING | 25000. | 0. | 0 | 0.000 |
| PIPING | 5367. | 3728. | 124 | 0.695 |
| CIVIL | 11442. | 8454. | 353 | 0.739 |
| STRUCTURAL STEEL | 6958. | 1502. | 57 | 0.216 |
| INSTRUMENTATION | 4542. | 2155. | 70 | 0.474 |
| ELECTRICAL | 1052. | 701. | 24 | 0.667 |
| INSULATION | 0. | 0. | 0 | 0.000 |
| PAINT | 1642. | 4633. | 203 | 2.821 |
| SUBTOTAL | 56004. | 21173. | 831 | 0.378 |

INSTALLED DIRECT COST 77200. INST'L COST/PE RATIO 3.088

**Fig 5.41: Economic Evaluation report of V-103-Tail Gas Storage Tank**

## 5.1.3 Equipment Costing:

Aspen PEA generates the purchase and installed cost of every equipment entity individually. For the Adsorption Column X-100, by dragging down about one third of the way down the report, the following summary page of the cost estimates could be located (Fig 5.42).

| | MATERIAL | MANPOWER | | L/M RATIO |
|---|---|---|---|---|
| | USD | USD | MANHOURS | USD/USD |
| EQUIPMENT&SETTING | 53100. | 8746. | 282 | 0.165 |
| PIPING | 24283. | 10586. | 351 | 0.436 |
| CIVIL | 3887. | 4118. | 168 | 1.059 |
| STRUCTURAL STEEL | 12753. | 2161. | 77 | 0.169 |
| INSTRUMENTATION | 7262. | 5838. | 189 | 0.804 |
| ELECTRICAL | 1867. | 1038. | 35 | 0.556 |
| INSULATION | 0. | 0. | 0 | 0.000 |
| PAINT | 1633. | 3091. | 139 | 1.892 |
| SUBTOTAL | 104787. | 35577. | 1241 | 0.340 |

INSTALLED DIRECT COST 140400. INST'L COST/PE RATIO 2.644

**Fig 5.42: Economic Evaluation result for X-100-Adsorption column from Aspen PEA**

It should be witnessed that the adsorption column designed by Aspen PEA generates a Purchased (Equipment and Setting) Cost of \$53100 (Rs. 33,47,955 for \$1=Rs.63.05) and the Installed Direct Cost of \$140400 (Rs. 88,52,220), that comprises of the cost of the column and locate it in place of its foundation (civil). Amid this stage, the planner could witness the outcome of modifications implied in the design specifications over these generated costs for the unit. Total Material and Manpower Cost is termed to be the cost of the equipment item and the direct cost of installation materials and labor (directly related to the equipment item). They comprise of the piping and field instruments that would fetch the process streams towards and through the tower, the foundation to support the column, structural steel, electrical lighting, cable, insulation, local components, heat trace, piping and fireproofing. It does not consists of: i. the fractional cost of buildings, pipe racks, the project control system or electrical substation, fire control systems, chemical and storm sewers and drains, treatment systems, fences, guard houses, etc., ii. taxes, freight to the site, permits, royalties, etc, iii. the work required to perform basic and detail engineering, to procure all project components, and to manage the engineering process, and.

Also, the Help menu provides the information on cost basis under the Show Cost Basis selection. Similarly, the economic evaluation results for other process equipment connected are given in Fig 5.38, Fig 5.39, Fig 5.40 and Fig 5.41.

### 5.1.4 Capital Cost Evaluation Procedure:

The generated reports by Aspen PEA does not comprise of indirect costs, contractor engineering costs, intra-plant piping and cost of pipe racks, and also the cost of drainage, that could be entered to the project as extra entities. These costs are mounted for each zone that holds the project components and are figured out for the entire project under Aspen Capital Cost Estimator (Aspen CCE). This is accomplished as follows.

i. Copy the .izp file of the PSA project file from the Temp folder of the system's C-drive and paste it in the desired Aspen Process Economic Analyzer folder in the same C-drive.
ii. By doing this, the project automatically gets generated in Aspen CCE with the same design parameters and data developed in Aspen PEA.
iii. The List Window in Aspen CCE appears as shown in Fig 5.43
iv. In the Project View section of Project Explorer, the entire equipment list must appear in Miscellaneous Flowsheet Area as shown in Fig 5.44. If any item appears in the New Item Area, drag and drop that item from the New Item Area to the Miscellaneous Flowsheet Area. When this is done, that item will get similar blue

check-in and will be under the list of project components under capital cost evaluation.

v. Now, the equipment can be individually evaluated as well as the overall plant cost can be generated by selecting the Evaluate Project  option, to generate the capital cost of the project.

vi. The capital cost evaluation report appears as shown in Fig 5.45

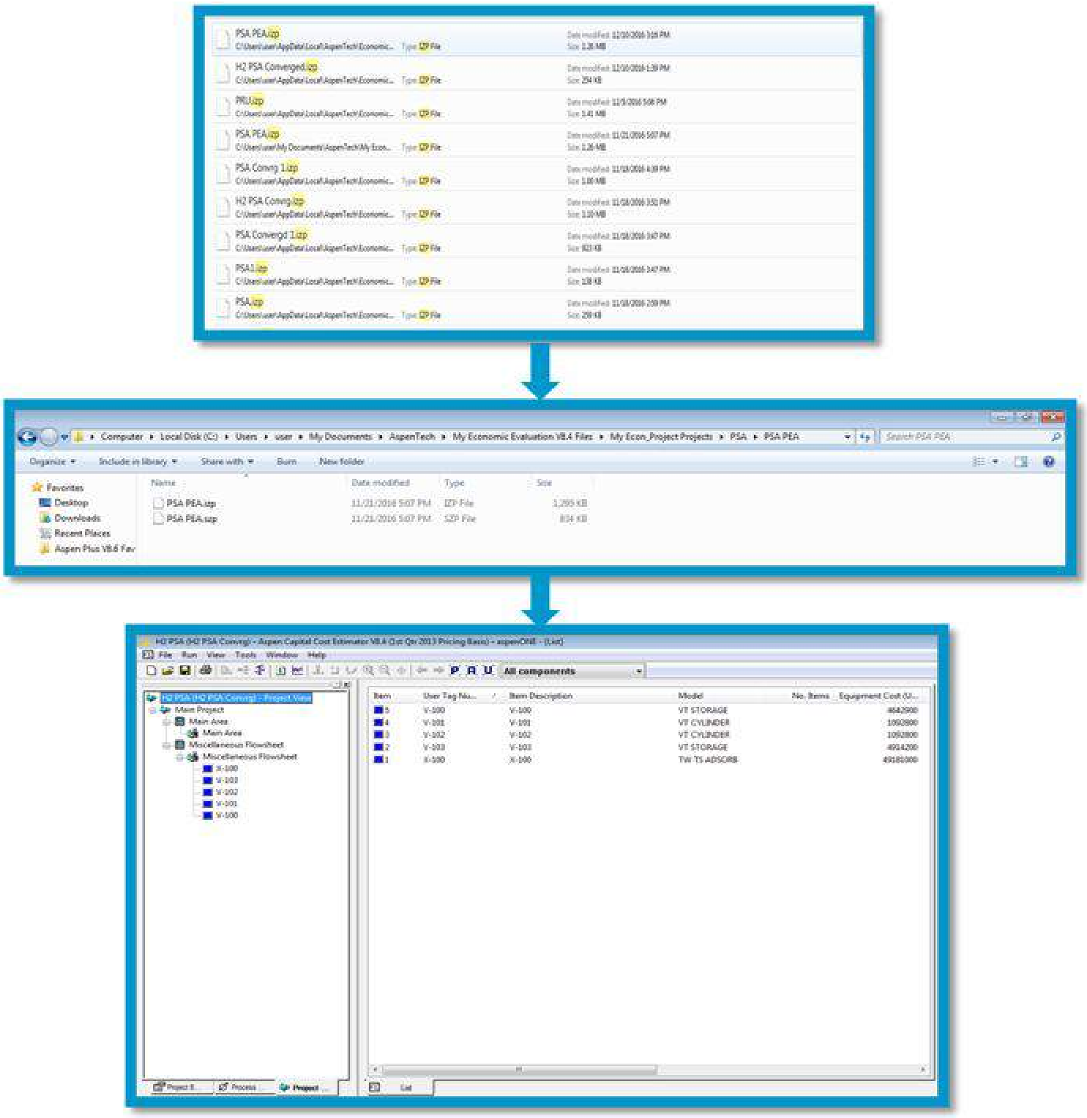



**Fig 5.43: Project Export procedure from Aspen PEA to Aspen CCE**

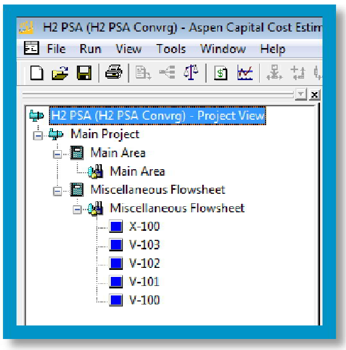



**Fig 5.44: Project Explorer section on Aspen CCE**

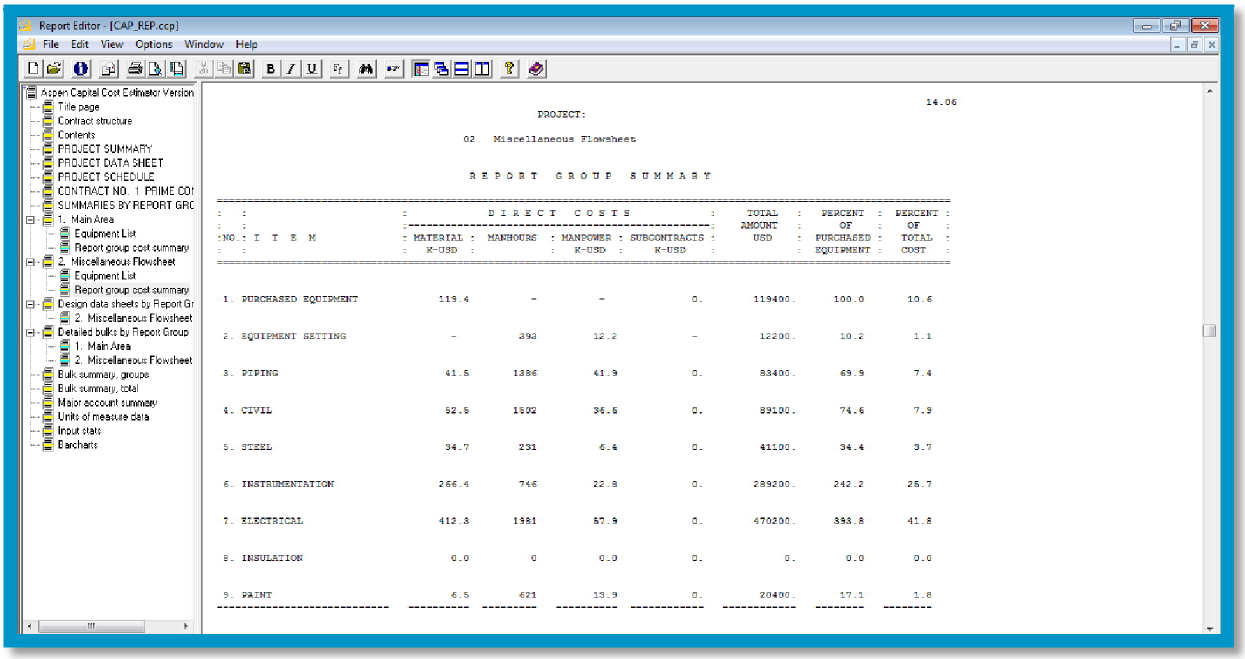
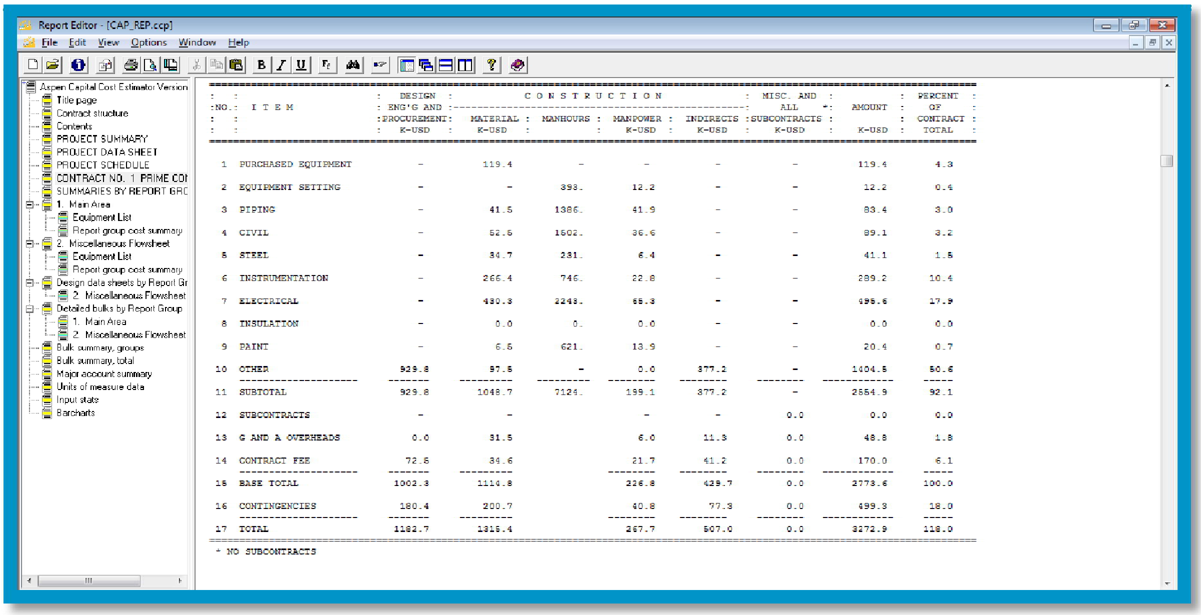



**Fig 5.45: Capital cost evaluation report for PSA on Aspen CCE**

It is to be mentioned that the entry for the purchased equipment (Fig 5.46) was $119400, from line 1, (Rs.75,28,170) for the sum of one adsorption column including other supporting piece of equipments recorded above. The overall direct material and manpower cost for construction of plant reported by Aspen CCE were $1048700 (Rs.6,61,20,535) and $199100 (Rs.1,25,53,255), as shown in line 11 of Fig 5.46. It is to be highlighted here that the installation charges for the equipment entities would be displayed on the List View (Fig 5.43).



| NO. | ITEM | DESIGN ENG'G AND PROCUREMENT K-USD | CONSTRUCTION MATERIAL K-USD | MANHOURS | MANPOWER K-USD | INDIRECTS K-USD | MISC. AND ALL SUBCONTRACTS K-USD * | AMOUNT K-USD | PERCENT OF CONTRACT TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| 1 | PURCHASED EQUIPMENT | - | 119.4 | - | - | - | - | 119.4 | 4.3 |
| 2 | EQUIPMENT SETTING | - | - | 393. | 12.2 | - | - | 12.2 | 0.4 |
| 3 | PIPING | - | 41.5 | 1386. | 41.9 | - | - | 83.4 | 3.0 |
| 4 | CIVIL | - | 52.5 | 1502. | 36.6 | - | - | 89.1 | 3.2 |
| 5 | STEEL | - | 34.7 | 231. | 6.4 | - | - | 41.1 | 1.5 |
| 6 | INSTRUMENTATION | - | 266.4 | 746. | 22.8 | - | - | 289.2 | 10.4 |
| 7 | ELECTRICAL | - | 430.3 | 2243. | 65.3 | - | - | 495.6 | 17.9 |
| 8 | INSULATION | - | 0.0 | 0. | 0.0 | - | - | 0.0 | 0.0 |
| 9 | PAINT | - | 6.5 | 621. | 13.9 | - | - | 20.4 | 0.7 |
| 10 | OTHER | 929.8 | 97.5 | - | 0.0 | 377.2 | - | 1404.5 | 50.6 |
| 11 | SUBTOTAL | 929.8 | 1048.7 | 7124. | 199.1 | 377.2 | - | 2554.9 | 92.1 |
| 12 | SUBCONTRACTS | - | - | | - | - | 0.0 | 0.0 | 0.0 |
| 13 | G AND A OVERHEADS | 0.0 | 31.5 | | 6.0 | 11.3 | 0.0 | 48.8 | 1.8 |
| 14 | CONTRACT FEE | 72.5 | 34.6 | | 21.7 | 41.2 | 0.0 | 170.0 | 6.1 |
| 15 | BASE TOTAL | 1002.3 | 1114.8 | | 226.8 | 429.7 | 0.0 | 2773.6 | 100.0 |
| 16 | CONTINGENCIES | 180.4 | 200.7 | | 40.8 | 77.3 | 0.0 | 499.3 | 18.0 |
| 17 | TOTAL | 1182.7 | 1315.4 | | 267.7 | 507.0 | 0.0 | 3272.9 | 118.0 |

* NO SUBCONTRACTS

**Fig 5.46: Capital cost summary in the evaluated report**

As soon as the information available from the database and Aspen Economic Package, we should generate the standard equipment charges scaling database page. Through these entries MS Excel would require the remaining essential information from the Aspen Package (Aspen HYSYS, Aspen PEA and Aspen CCE) results page and the database of equipment cost inquiry outcome page.

At the end, the spreadsheet would result the overall equipment charges and also evaluate the installation costs as shown in Table 5.4. Mentioning these many financial datas (kept constant for all choices), the results reported through Aspen Package were validated through this MS Excel database and the total equipment cost was Rs. 2,77,31,000 (excluding the adsorption column packing material cost). When compared to estimated equipment cost of Rs.2,87,38,696 (provided by HPCL R&D, Process Design and Scale-up department for the already installed PSA project), the acquired results highly matched with percentage difference of -3.51%. The overall capital cost estimation reported through Aspen CCE, as a result of comparison with estimated cost of the PSA project by HPCL R&D, highly matched with minute difference of 2.26 %.

**Table 5.4: MS Excel Database generated for the validation of capital cost results of PSA**

| | | *Figures in Rs. Lakhs* | | | | |
|---|---|---|---|---|---|---|
| Sr. No. | Description | Estimated Cost | Estimation through Aspen CCE | | | |
| | | in Rs. Lakshs | in Rs. Lakhs | in Dollars | Difference | Difference in % |
| 1 | Adsorption Tower (6 nos.), Product Surge Tank (1)(, Tail Gas Storage Tank(1), Product Demister (1), Tail Gas Demister (1) | 287.39 | 277.31 | 439820.00 | -10.08 | -3.51 |
| 2 | Steel Structure, Piping Work/Mechanical works | 479.59 | 423.82 | 672196.80 | -55.77 | -11.63 |
| 3 | Electical & Instrumentation | 587.93 | 604.22 | 958320.00 | 16.29 | 2.77 |
| 4 | Civil Foundation | 234.00 | 224.73 | 356424.00 | -9.28 | -3.96 |
| 7 | Engineering Cost | 710.69 | 821.54 | 1302990.00 | 110.85 | 15.60 |
| **8** | **Grand Total** | **2299.60** | **2351.61** | **3729750.80** | 52.01 | 2.26 |
| **9** | **Grand Total (in Rupees Crores)** | **23.00** | **23.52** | **37297.51** | 0.52 | 2.26 |
| **Exclusions** | | | | | | |
| 1 | PLC & Programming | | | | | |
| 2 | Purge Gas Compressor | | | | | |
| 3 | Contingency | | | | | |
| 4 | Tax | | | | | |

## 5.2 ECONOMIC EVALUATION OF PROPYLENE DRYER UNIT (PDU):

A case study for the capital cost estimation of PDU was carried through the same procedure followed for PSA unit economic evaluation. The PDU model generated with the specification and composition mentioned under Methodology (Chapter 4, Section 4.2), is as shown in Fig 5.48.

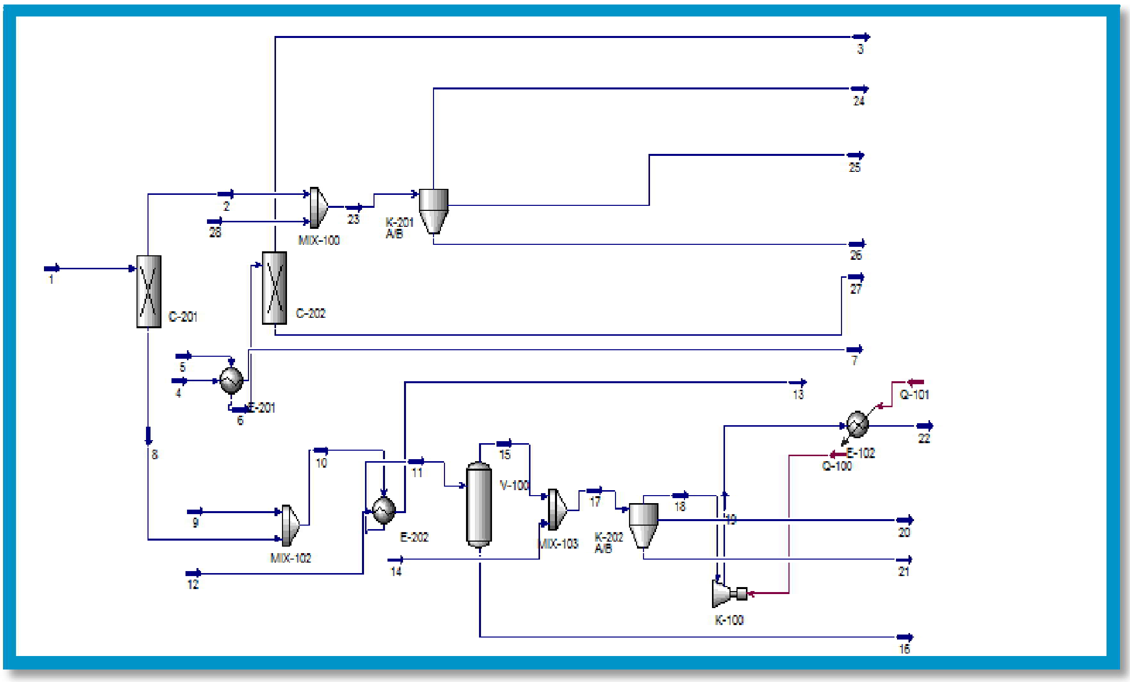



**Fig 5.47: PDU Model generated on Aspen HYSYS**

On adopting the exact procedure carried out for PSA with the same initial cost element specifications, the economic and capital cost evaluation results from Aspen PEA and Aspen CCE for PDU were as shown in Fig 5.49 to Fig 5.57. The main window on Aspen PEA appeared to be as in Fig 5.48 for PDU.

On observing the evaluated results, for C-201 column, Aspen PEA furnished the Purchased (Equipment and Setting) Cost of $142154 (Rs. 89,62,809), with the exclusions mentioned on Table 5.4. The results from Aspen CCE were also recorded and the overall plant cost recorded by the Aspen CCE report was $769231 (Rs. 4,85,00,000 approx.), with exclusions mentioned on Table 5.4.

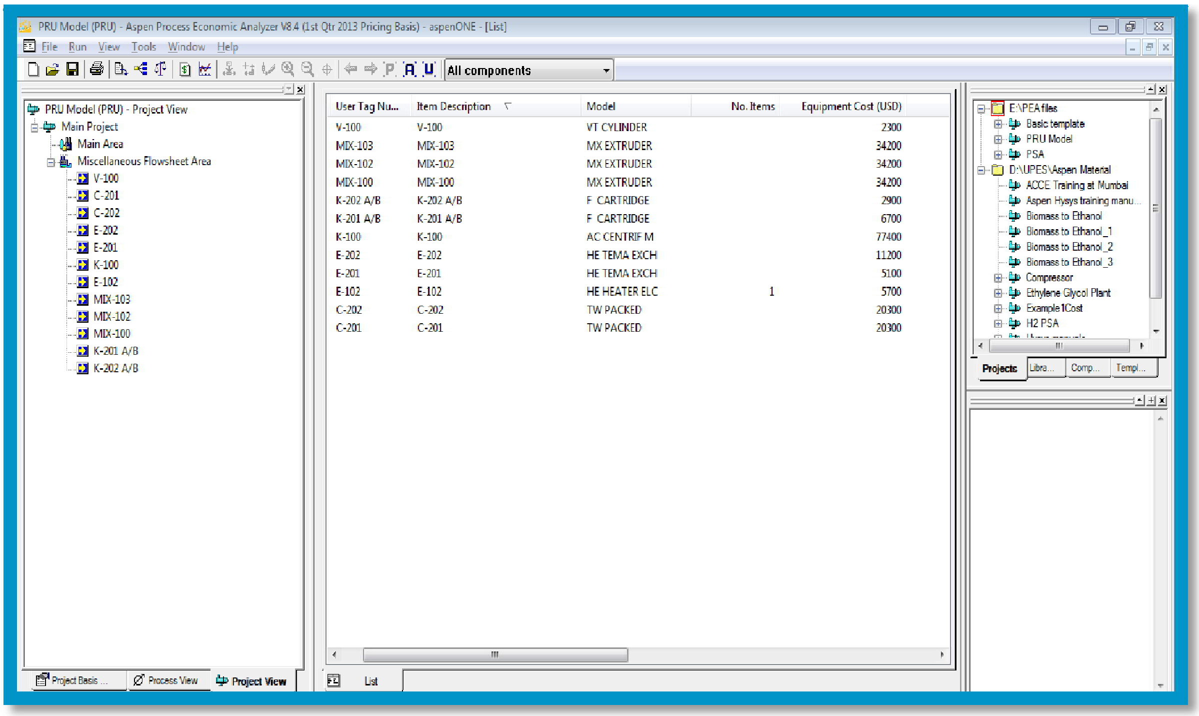



**Fig 5.48: Main Window on Aspen PEA for PDU simulated model**

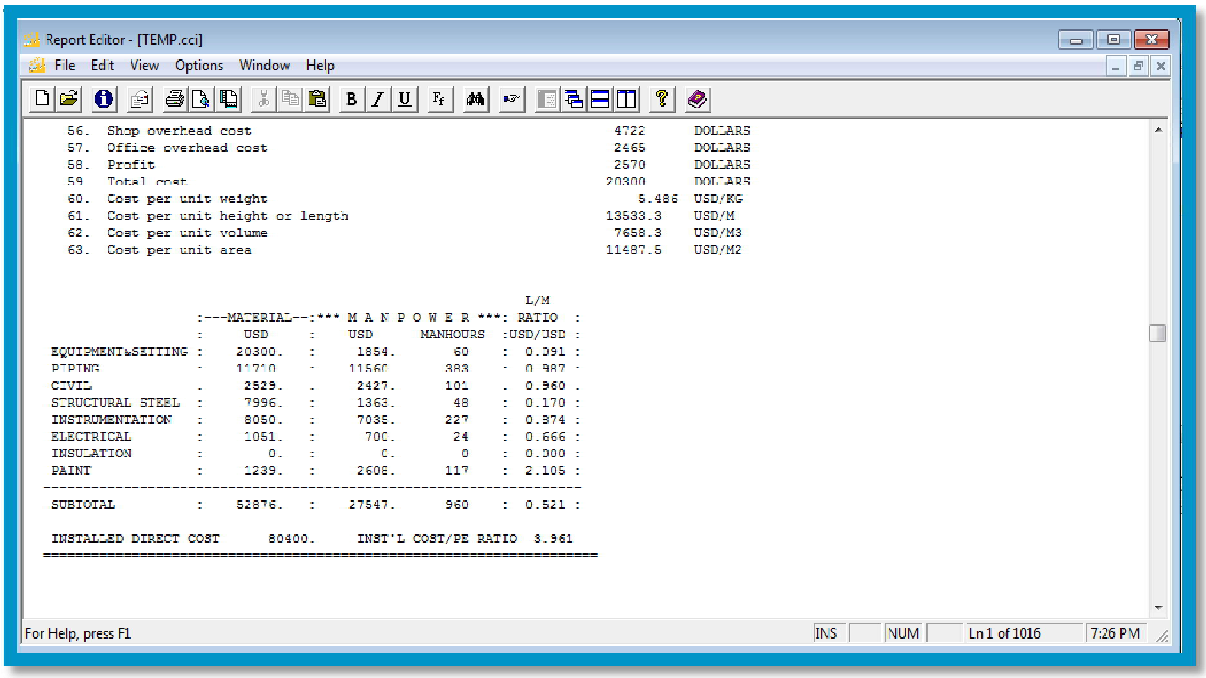
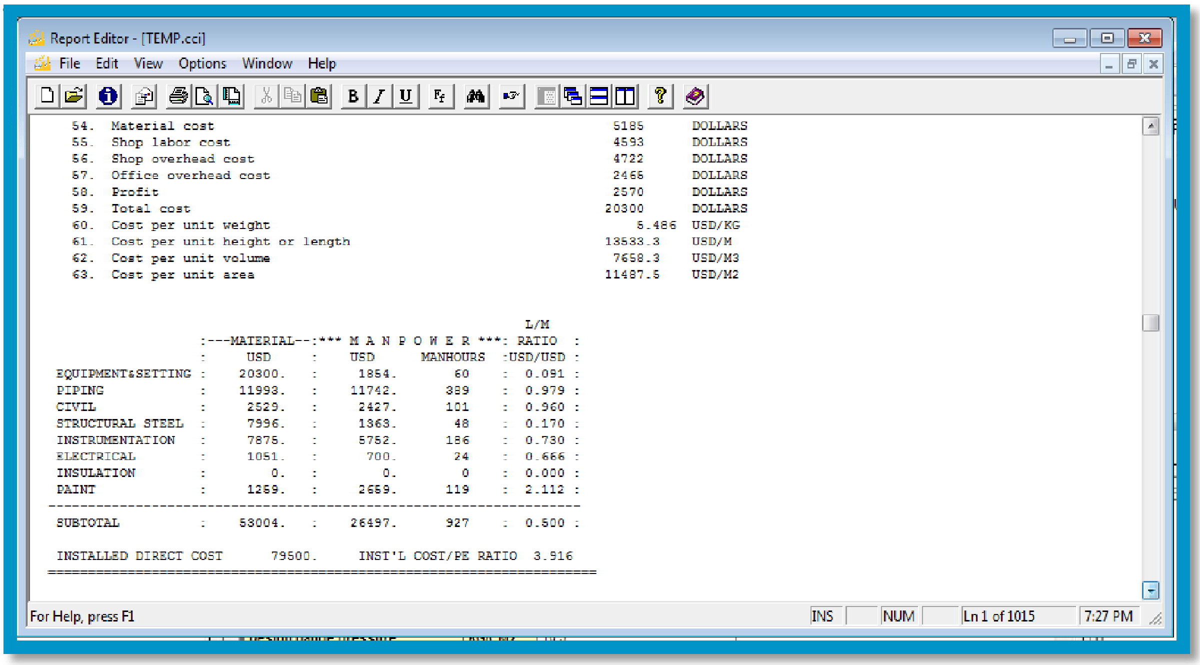



**Fig 5.49: Economic Evaluation report of C-201-Column**



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| | | | |
|---|---|---|---|
| 54. | Material cost | 5185 | DOLLARS |
| 55. | Shop labor cost | 4593 | DOLLARS |
| 56. | Shop overhead cost | 4722 | DOLLARS |
| 57. | Office overhead cost | 2465 | DOLLARS |
| 58. | Profit | 2570 | DOLLARS |
| 59. | Total cost | 20300 | DOLLARS |
| 60. | Cost per unit weight | 5.486 | USD/KG |
| 61. | Cost per unit height or length | 13533.3 | USD/M |
| 62. | Cost per unit volume | 7658.3 | USD/M3 |
| 63. | Cost per unit area | 11487.5 | USD/M2 |

| | MATERIAL USD | MANPOWER USD | MANPOWER MANHOURS | L/M RATIO USD/USD |
|---|---|---|---|---|
| EQUIPMENT&SETTING | 20300. | 1854. | 60 | 0.091 |
| PIPING | 11993. | 11742. | 389 | 0.979 |
| CIVIL | 2529. | 2427. | 101 | 0.960 |
| STRUCTURAL STEEL | 7996. | 1363. | 48 | 0.170 |
| INSTRUMENTATION | 7875. | 5752. | 186 | 0.730 |
| ELECTRICAL | 1051. | 700. | 24 | 0.666 |
| INSULATION | 0. | 0. | 0 | 0.000 |
| PAINT | 1259. | 2659. | 119 | 2.112 |
| SUBTOTAL | 53004. | 26497. | 927 | 0.500 |

INSTALLED DIRECT COST 79500. INST'L COST/PE RATIO 3.916

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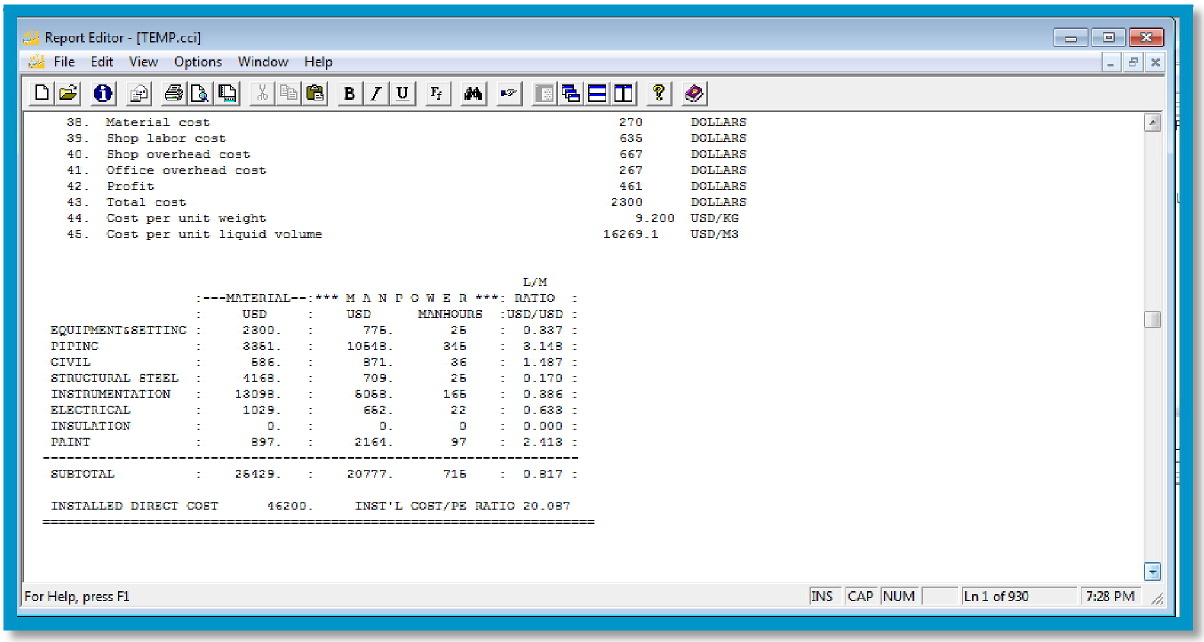
**Fig 5.50: Economic Evaluation report of C-202-Column**



Report Editor - [TEMP.cci]

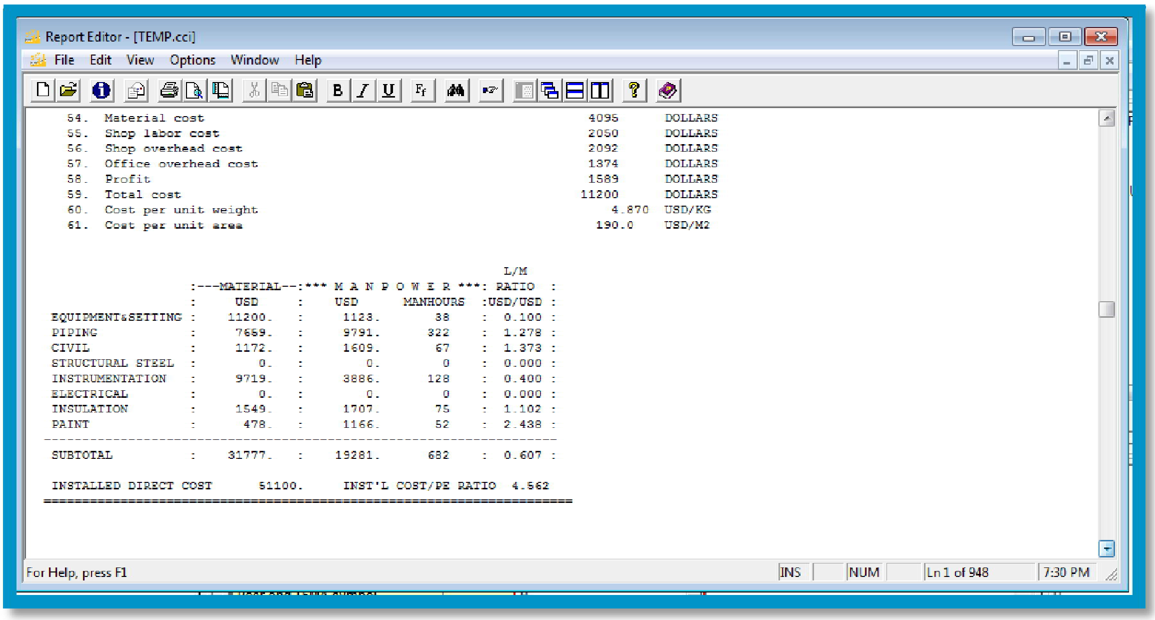
| | | | |
|---|---|---|---|
| 38. | Material cost | 270 | DOLLARS |
| 39. | Shop labor cost | 635 | DOLLARS |
| 40. | Shop overhead cost | 667 | DOLLARS |
| 41. | Office overhead cost | 267 | DOLLARS |
| 42. | Profit | 461 | DOLLARS |
| 43. | Total cost | 2300 | DOLLARS |
| 44. | Cost per unit weight | 9.200 | USD/KG |
| 45. | Cost per unit liquid volume | 16269.1 | USD/M3 |

| | MATERIAL USD | MANPOWER USD | MANPOWER MANHOURS | L/M RATIO USD/USD |
|---|---|---|---|---|
| EQUIPMENT&SETTING | 2300. | 775. | 25 | 0.337 |
| PIPING | 3351. | 10548. | 345 | 3.148 |
| CIVIL | 586. | 871. | 36 | 1.487 |
| STRUCTURAL STEEL | 4168. | 709. | 25 | 0.170 |
| INSTRUMENTATION | 13098. | 5058. | 165 | 0.386 |
| ELECTRICAL | 1029. | 652. | 22 | 0.633 |
| INSULATION | 0. | 0. | 0 | 0.000 |
| PAINT | 897. | 2164. | 97 | 2.413 |
| SUBTOTAL | 25429. | 20777. | 715 | 0.817 |

INSTALLED DIRECT COST 46200. INST'L COST/PE RATIO 20.087

For Help, press F1 | INS | CAP | NUM | Ln 1 of 930 | 7:28 PM

**Fig 5.51: Economic Evaluation report of V-100-Water Separator**



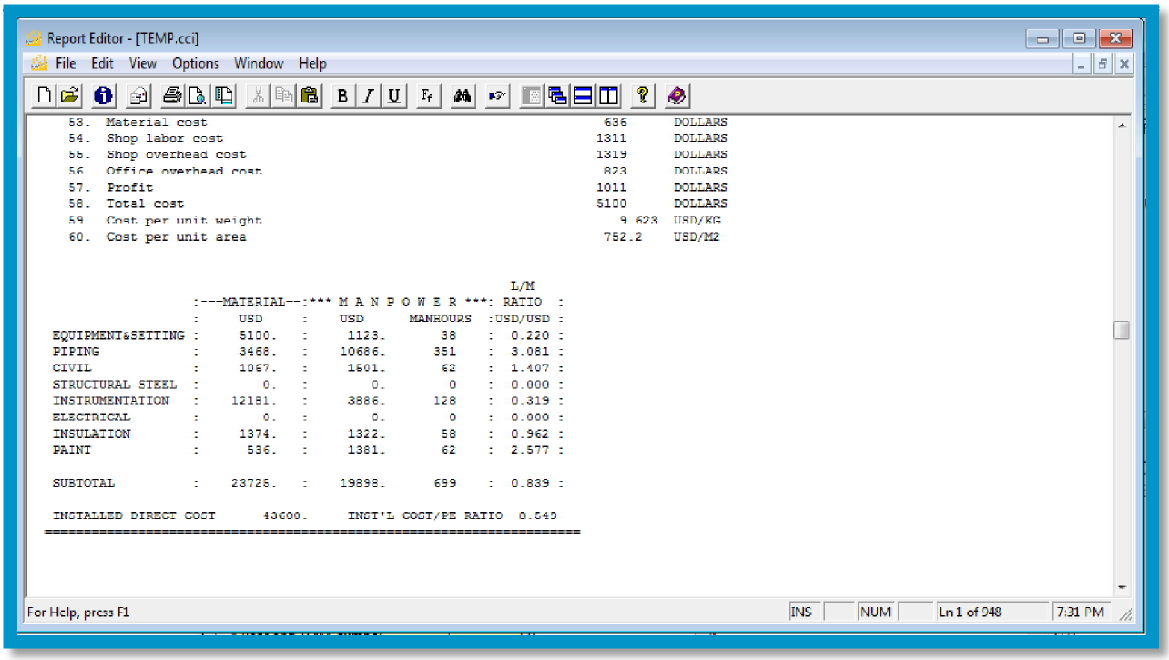


| | | | |
|---|---|---|---|
| 54. | Material cost | 4095 | DOLLARS |
| 55. | Shop labor cost | 2050 | DOLLARS |
| 56. | Shop overhead cost | 2092 | DOLLARS |
| 57. | Office overhead cost | 1374 | DOLLARS |
| 58. | Profit | 1589 | DOLLARS |
| 59. | Total cost | 11200 | DOLLARS |
| 60. | Cost per unit weight | 4.870 | USD/KG |
| 61. | Cost per unit area | 190.0 | USD/M2 |

| | MATERIAL | MANPOWER | | L/M RATIO |
|---|---|---|---|---|
| | USD | USD | MANHOURS | USD/USD |
| EQUIPMENT&SETTING | 11200. | 1123. | 38 | 0.100 |
| PIPING | 7659. | 9791. | 322 | 1.278 |
| CIVIL | 1172. | 1609. | 67 | 1.373 |
| STRUCTURAL STEEL | 0. | 0. | 0 | 0.000 |
| INSTRUMENTATION | 9719. | 3886. | 128 | 0.400 |
| ELECTRICAL | 0. | 0. | 0 | 0.000 |
| INSULATION | 1549. | 1707. | 75 | 1.102 |
| PAINT | 478. | 1166. | 52 | 2.438 |
| SUBTOTAL | 31777. | 19281. | 682 | 0.607 |

INSTALLED DIRECT COST 51100. INST'L COST/PE RATIO 4.562

**Fig 5.52: Economic Evaluation report of E-201-Regeneration Gas Cooler**



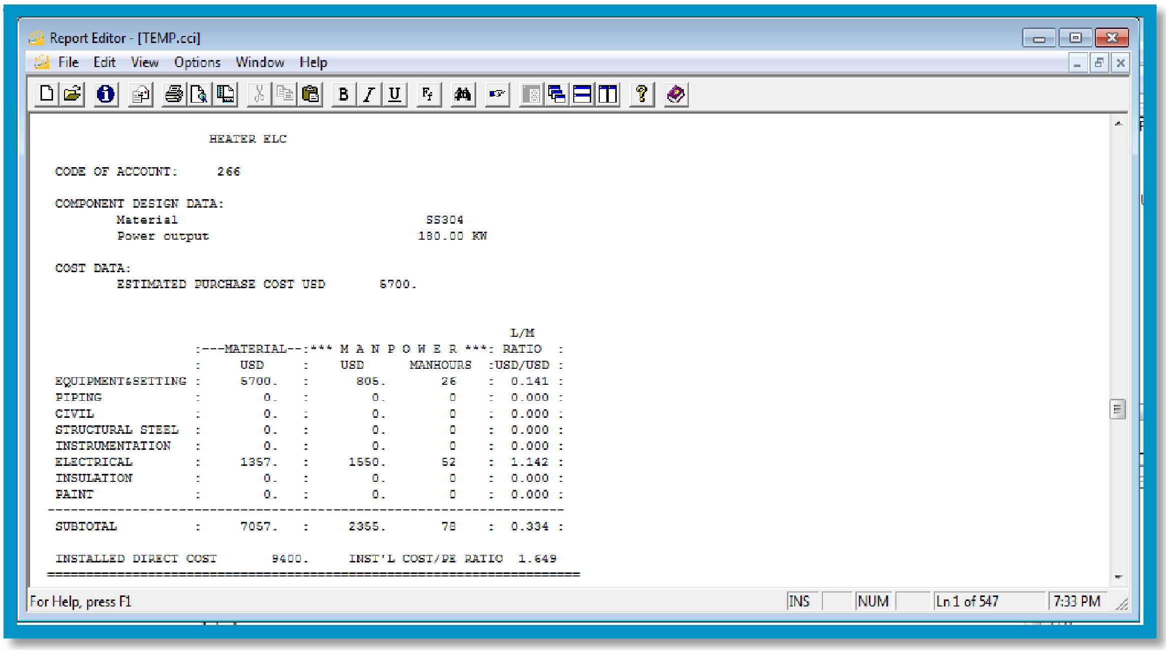


| | | | |
|---|---|---|---|
| 53. | Material cost | 636 | DOLLARS |
| 54. | Shop labor cost | 1311 | DOLLARS |
| 55. | Shop overhead cost | 1319 | DOLLARS |
| 56. | Office overhead cost | 823 | DOLLARS |
| 57. | Profit | 1011 | DOLLARS |
| 58. | Total cost | 5100 | DOLLARS |
| 59. | Cost per unit weight | 9.623 | USD/KG |
| 60. | Cost per unit area | 752.2 | USD/M2 |

| | MATERIAL | MANPOWER | | L/M RATIO |
|---|---|---|---|---|
| | USD | USD | MANHOURS | USD/USD |
| EQUIPMENT&SETTING | 5100. | 1123. | 38 | 0.220 |
| PIPING | 3468. | 10686. | 351 | 3.081 |
| CIVIL | 1067. | 1501. | 62 | 1.407 |
| STRUCTURAL STEEL | 0. | 0. | 0 | 0.000 |
| INSTRUMENTATION | 12181. | 3886. | 128 | 0.319 |
| ELECTRICAL | 0. | 0. | 0 | 0.000 |
| INSULATION | 1374. | 1322. | 58 | 0.962 |
| PAINT | 536. | 1381. | 62 | 2.577 |
| SUBTOTAL | 23725. | 19898. | 699 | 0.839 |

INSTALLED DIRECT COST 43600. INST'L COST/PE RATIO 0.549

**Fig 5.53: Economic Evaluation report of E-202-Propylene Vaporizer**



HEATER ELC

CODE OF ACCOUNT: 266

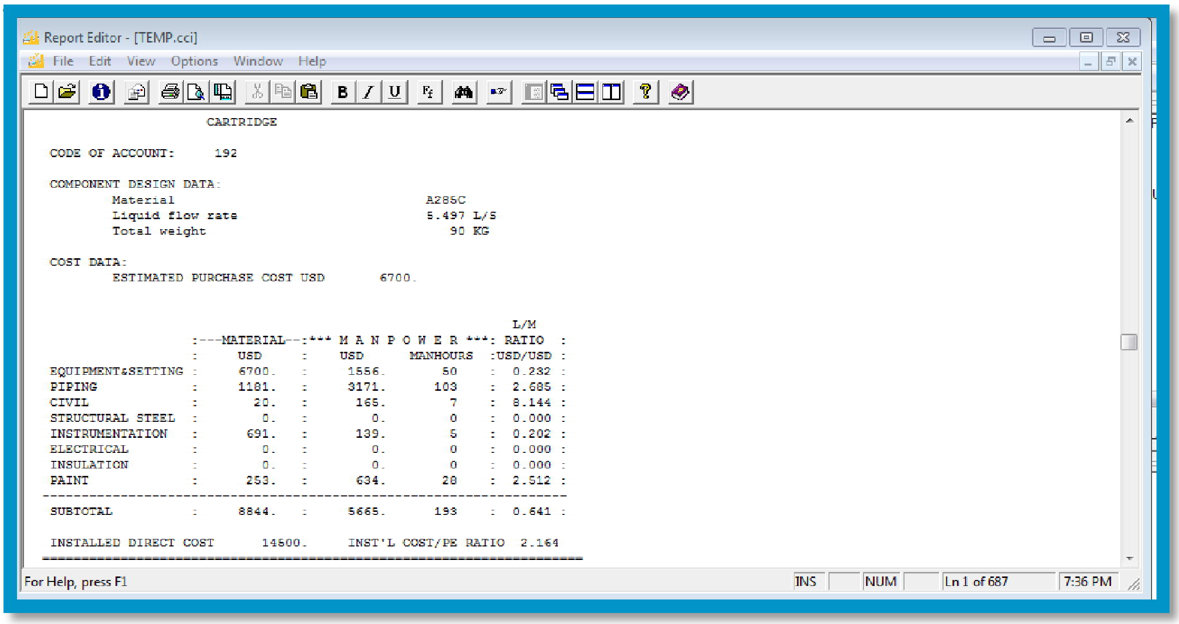
COMPONENT DESIGN DATA:
Material SS304
Power output 180.00 KW

COST DATA:
ESTIMATED PURCHASE COST USD 6700.

| | MATERIAL USD | MANPOWER USD | MANHOURS | L/M RATIO USD/USD |
|---|---|---|---|---|
| EQUIPMENT&SETTING | 6700. | 805. | 26 | 0.141 |
| PIPING | 0. | 0. | 0 | 0.000 |
| CIVIL | 0. | 0. | 0 | 0.000 |
| STRUCTURAL STEEL | 0. | 0. | 0 | 0.000 |
| INSTRUMENTATION | 0. | 0. | 0 | 0.000 |
| ELECTRICAL | 1357. | 1550. | 52 | 1.142 |
| INSULATION | 0. | 0. | 0 | 0.000 |
| PAINT | 0. | 0. | 0 | 0.000 |
| SUBTOTAL | 7057. | 2355. | 78 | 0.334 |

INSTALLED DIRECT COST 9400. INST'L COST/PE RATIO 1.649

**Fig 5.54: Economic Evaluation report of E-102-$N_2$ Electric Heater**



CARTRIDGE

CODE OF ACCOUNT: 192

COMPONENT DESIGN DATA:
Material A285C
Liquid flow rate 5.497 L/S
Total weight 90 KG

COST DATA:
ESTIMATED PURCHASE COST USD 6700.

| | MATERIAL USD | MANPOWER USD | MANHOURS | L/M RATIO USD/USD |
|---|---|---|---|---|
| EQUIPMENT&SETTING | 6700. | 1556. | 50 | 0.232 |
| PIPING | 1181. | 3171. | 103 | 2.685 |
| CIVIL | 20. | 165. | 7 | 8.144 |
| STRUCTURAL STEEL | 0. | 0. | 0 | 0.000 |
| INSTRUMENTATION | 691. | 139. | 5 | 0.202 |
| ELECTRICAL | 0. | 0. | 0 | 0.000 |
| INSULATION | 0. | 0. | 0 | 0.000 |
| PAINT | 253. | 634. | 28 | 2.512 |
| SUBTOTAL | 8844. | 5665. | 193 | 0.641 |

INSTALLED DIRECT COST 14600. INST'L COST/PE RATIO 2.164

**Fig 5.55: Economic Evaluation report of K-201A/B-Filter**

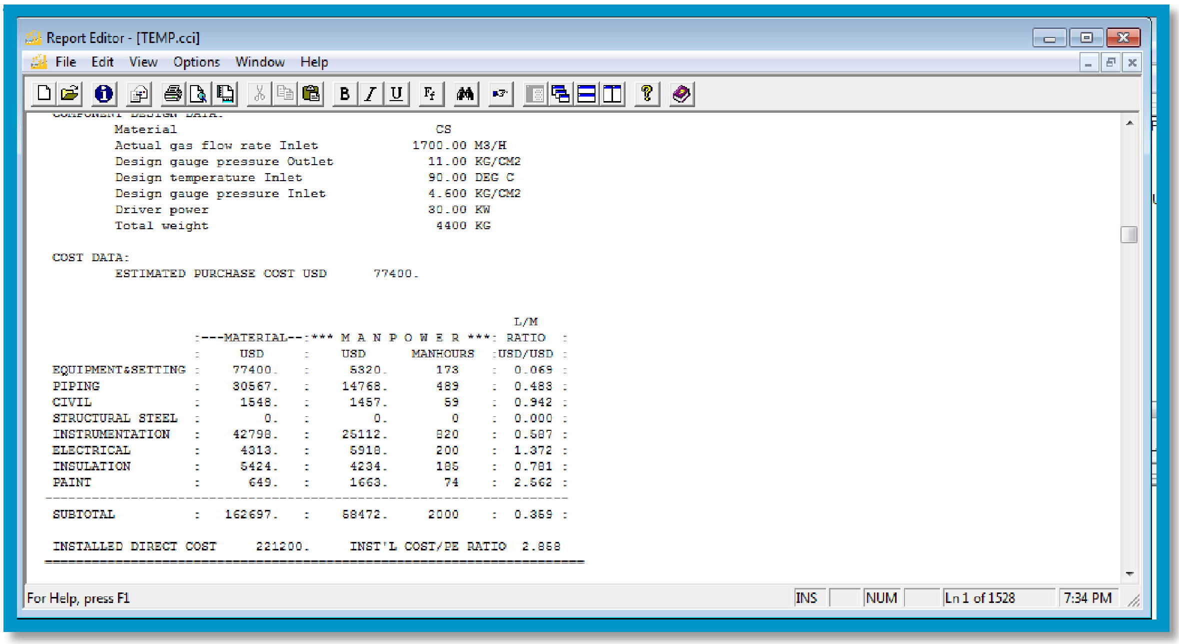



**Fig 5.56: Economic Evaluation report of K-100-Root Blower**

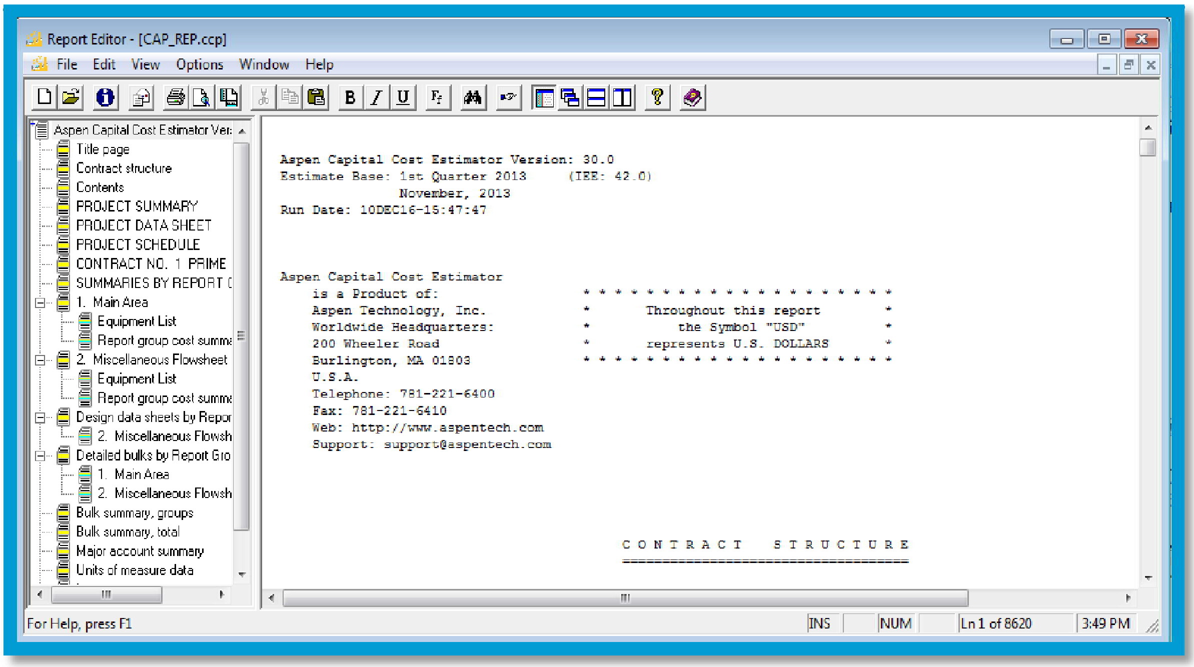



**Fig 5.57: Capital cost evaluation report of PRU on Aspen CCE**

The MS Excel spreadsheet format already generated by HPCL R&D with the total equipment and installed costs was recorded and validated with the previous estimated data as in Fig 5.59. When compared to estimated equipment cost of Rs.4.86 crores (provided by HPCL R&D, Process Design and Scale-up department for the previously revised estimation), the acquired results through Aspen CCE (Rs.4.85 crores) chiefly convinced with -0.21 percentage difference insignificant variation.

The case study of PDU was carried out in order to get the clarity and confirmation of the opted approach to land-up the estimated result of the unit and the results of PDU through this course of channel furnished the accuracy with the already available estimated data.

**Table 5.5: MS Excel Database generated for the validation of capital cost results of PDU**

| | | *Figures in Rs. Lakhs* | | | | |
|---|---|---|---|---|---|---|
| **Sr. No.** | **Description** | **Estimated Cost** | **Estimation through Aspen CCE** | | | |
| | | **in Rs. Lakshs** | **in Rs. Lakhs** | **in Dollars** | **Difference** | **Difference in %** |
| 1 | Adsorption Tower (2 nos.), Propylene Vaporizer (1 no.), Regeneration Gas Cooler (1 no.), Water Separator (1 no.), (Root Blower), Product Filter (1 no.), Blower Filter (1 no.), Nitrogen Electric Heater (1 no.) | 85.80 | 89.63 | 142154.00 | 3.83 | 4.46 |
| 2 | Steel Structure, Piping Work/Mechanical works and Painting | 176.80 | 155.95 | 247346.00 | -20.85 | -11.79 |
| 3 | Electical & Instrumentation | 169.48 | 178.75 | 283503.00 | 9.26 | 5.47 |
| 4 | Civil Foundation | 20.90 | 26.88 | 42634.00 | 5.98 | 28.62 |
| 7 | Engineering Cost | 33.00 | 33.73 | 53500.00 | 0.73 | 2.22 |
| **8** | **Grand Total** | **485.98** | **484.94** | **769137.00** | -1.04 | -0.21 |
| **9** | **Grand Total (in Rupees Crores)** | **4.86** | **4.85** | **7691.37** | -0.01 | -0.21 |
| **Exclusions** | | | | | | |
| 1 | Equipments- Miscellaneous item allowance, PLC & Programming and warehouse spares | | | | | |
| 2 | Electical- Wire/Cable-HV, Motor Control Center-LV, Switchgear-MV, Switchgear-LV, Disconnect switch, Transformers-HV, Switchgear-HV, Bus Duct-MV/HV, Substation steel, Miscellaneous small transformers, Electrical trenching.<br>Instrumentation- Other instruments electrical, Controller interfaces, Operator stations. | | | | | |
| 3 | Civil Foundation- Other Equipment Concrete | | | | | |
| 4 | Engineering Cost- Contingency, Tax | | | | | |

## 5.3 BASE CASE EQUIPMENT DATABASE (PSA):

**Table 5.6: Equipment Database for PSA generated through the Aspen PEA results and Vendor Quote.**

| S.No | Equipments | Qty | Unit Rate on Aspen PEA | Total Price on Aspen PEA | Unit Rate Quoted by Vendor | Total Price Quoted by Vendor | Difference | Percentage Difference |
|---|---|---|---|---|---|---|---|---|
| | | | Rs. | Rs. | Rs. | Rs. | | |
| 1 | Adsorption Column | 1 | 3,886,780.00 | 3,886,780.00 | 3,675,000.00 | 3,675,000.00 | 211,780.00 | 5.763 |
| 2 | Adsorption Column | 5 | 3,886,780.00 | 19,433,900.00 | 3,675,000.00 | 18,375,000.00 | 1,058,900.00 | 5.763 |
| 3 | Product Gas Storage Tank | 1 | 1,670,446.00 | 1,670,446.00 | 11,780,000.00 | 11,780,000.00 | (10,109,554.00) | -85.820 |
| 4 | Tail Gas Storage Tank | 1 | 1,576,250.00 | 1,576,250.00 | 4,100,000.00 | 4,100,000.00 | (2,523,750.00) | -61.555 |
| 5 | Product Demister | 1 | 471299 | 471,299.00 | 400,000.00 | 400,000.00 | 71,299.00 | 17.825 |
| 6 | Tail Gas Demister | 1 | 471299 | 471,299.00 | 325,000.00 | 325,000.00 | 146,299.00 | 45.015 |
| Total Equipment Cost | | | | 27,509,974.00 | | 38,655,000.00 | (11,145,026.00) | -28.832 |

The capital costs for this section were evaluated using Aspen Process Economic Analyzer (Aspen PEA) and vendor budgetary estimate. As declared by *Symister*, this is most largely the exact way to generate and estimate the purchase cost of the entities of equipment, by producing the latest quote from the appropriate vendor. The accuracy of the tabulated datas of equipment cost may be no superior than ±25%, and so the estimating procedure depending on these data can solely be implied for preliminary estimates. Since, the quote submitted by the vendor were only for the equipments with the current margin, the economic evaluation results of the equipments from Aspen PEA were considered to generate this database. For the PSA unit for the design conditions (Table 4.1) provided to the vendors, the estimation for the equipments was generated and submitted by the vendor, considering the current (2016) margin.

The original (base) purchased equipment costs (provided by HPCL R&D), reflects the preliminary instance for equipment size and cost year. It is to be mentioned that the entry for the total purchased equipment mentioned under ACCE column was Rs. 2,75,09,974, whereas the quoted price offer by the vendor was observed to be Rs. 3,86,55,000. These evaluation facilitated in proving the efficient preliminary estimation and evaluation of a project proposal. The percentage difference of the PSA unit equipment cost from Table 5.4 was -28.83% (*Towler and Sinnott's* factorial method satisfied). The primary reason for the minor difference with the vendor quote and Aspen CCE estimation is due to the Chemical Engineering Plant Cost Index (CEPCI) value inbuilt in the Aspen PEA and Aspen CCE version of software (Appendix 1). The CEPCI value solitarily depends upon the location of project, which would be mentioned at the initial defining stage of the project in Aspen PEA. While developing the evaluation of PSA on Aspen, the currency and plant location was regarded for US dollar, since in Aspen V8.4, the exchange rates, COA and indices for INR and other currency factors were not updated to the existing rates

The exclusions conditioned by the vendor under their quote were as follows:

i. Unloading of equipment at site.
ii. Site development, receipt storage, shifting and necessary installation of plant and machinery.
iii. Building, civil work, necessary flooring, lighting, ventilation and other general amenities.
iv. Normal Operational Spares.
v. All type of approvals.
vi. Access Platform, ladder, etc.
vii. Any other equipment and services not expressly mentioned in their offer.

Fig 5.60 exhibits the terms and conditions and other terms of the vendor's quotation.

**3.0 COMMERCIAL TERMS AND CONDITIONS:**

**3.1 PRICE SUMMARY:**

Our Price for Engineering and supply of above listed equipments as per scope of supply is,

| Sr. No | Item | Qty | Unit Rate (Ex-Works Pune) | Total Price (Ex-Works Pune) |
|---|---|---|---|---|
| 1 | Adsorber-1 | 1 | INR 3,675,000 | INR 3,675,000 |
| 2 | Adsorber-2 | 5 | INR 3,675,000 | INR 18,375,000 |
| 3 | Product Gas Tank | 1 | INR 11,780,000 | INR 11,780,000 |
| 4 | Tail Gas Storage Tank | 1 | INR 4,100,000 | INR 4,100,000 |
| 5 | Product Demister | 1 | INR 400,000 | INR 400,000 |
| 6 | Tail Gas Demister | 1 | INR 325,000 | INR 325,000 |
| Total Cost | | | | INR 38,655,000 |
| IN WORDS (Ex-Works Pune): INR THREE CRORE EIGHTY SIX LAKH FIFTY FIVE THOUSAND ONLY | | | | |

**3.2 TERMS OF PAYMENT FOR SUPPLY OF EQUIPMENT**

40% advance along with the order by bank transfer
60% against readiness of goods at our works before dispatch

**3.3 DELIVERY:**

4-6 Months for supply Ex-Works Pune from the date of receipt of your technically and commercially clear purchase order along with the receipt of advance.
**However the delivery schedule can be discussed in order to meet the project schedule.**

**3.4 VALIDITY:**

This offer is valid for your acceptance for 60 days from the date hereof and thereafter subject to our written confirmation.

**3.5 INSPECTION:**

In case of inspection by any independent third party agency on equipment, charges for the same shall be extra at actual.

**3.6 GUARANTEE / WARRANTY**
**Warranty against Defects:**

CHEMDIST warranty all equipment offered by them against material, workmanship and manufacturing defects for a period of 24 months from the date of installation and commissioning.
CHEMDIST shall not be responsible for replacement or repairs for normal wear and tear of component

6



**Fig 5.58: Quote along with Terms and Conditions of Vendor's offer for PSA**

The new (foundation) purchased equipment (Table 5.5 costs displays the inital case for the equipment size and cost year. The required size of equipment for the process may differ from the earlier base states, entailed for adjustments of the equipment costs. In place of proceeding with re-pricing the equipment in similar cases after minute changes in size, exponential scaling could be implied to regulate the purchased cost of equipment using Eq. 5.1 [28]:

$$Scale - up\ Equipment\ Cost = Base\ Equipment\ Cost\ \left(\frac{Scale - up\ Capacity}{Base\ Capacity}\right)^{n} \quad \ldots 5.1$$

Wherein, the characteristic scaling exponent, n, typically ranges from 0.6 to 0.7 for process equipment. For this case, the sizing parameters were based on a feature of the equipment associated to production capacity, such as inlet flow for a process vessel or heat transfer duty. Eq. 5.1 assumes that all other process parameters (pressure, temperature etc.) remains constant relative to the base case. Scaling exponents were determined from the following sources:

i. Vendor's estimates of scaling exponent or inference from vendor quotes when multiple quotes were available for equipment of various processing capacities.
ii. Development of correlations by multiple estimates from ACCE software.
iii. Standard reference from published sources such as *Garett*, *Peters*, *Timmerhaus, and West, and Perry et al.*

# CHAPTER 6
# CONCLUSION

The project works involved familiarizing with the software tools available in Aspen Engineering Suite viz., HYSYS, PEA and CCE, and apply them to carry out cost estimation for a project. The case study involved in this report were, one pertaining to PSA plant and another to PDU.

The outcome of the economic evaluation through the stages explained above resulted in efficient feasibility and estimated outcome. Comparison of estimated cost with the project cost is indicated in Table 5.4 and 5.5 were tabulated and recorded.

The evaluation and estimation of the results obtained through Aspen CCE indicated about 2.3% difference with the estimated data of PSA. Whereas for PDU the estimated percentage difference was found to be about -0.2%. These results corrugated reasonable with the observation by Symister (2016) with minimal errors than the manual estimation directions traditionally pursued in industries.

As can be seen from the work, the tools available on Aspen engineering suite will be helpful in carrying out preliminary cost estimates with adequate accuracy.

# APPENDIX 1

## ECONOMIC INDICATORS (Economic Indicators Chart., 2015 and 2016)

**Table A 1.1 CEPCI for year 2013 and 2014**

| CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI) (1957-59=100) | | Oct'14 Prelim. | Sept'14 Final | Oct'13 Final |
|---|---|---|---|---|
| CE Index | | 579.8 | 580.1 | 567.5 |
| Equipment | | 704.1 | 704.6 | 686.6 |
| a. | Heat exchangers & tanks | 652.3 | 650.9 | 620.0 |
| b. | Process machinery | 666.9 | 668.1 | 655.7 |
| c. | Pipes, valves & fittings | 876.4 | 877.4 | 874.5 |
| d. | Process instruments | 411.9 | 413.4 | 411.8 |
| e. | Pumps & compressors | 941.1 | 939.0 | 924.7 |
| f. | Electrical equipment | 516.0 | 515.7 | 513.8 |
| g. | Structural supports & misc | 769.1 | 775.1 | 744.1 |
| Construction labor | | 324.4 | 323.9 | 321.6 |
| Buildings | | 547.2 | 546.3 | 533.7 |
| Engineering & supervision | | 320.3 | 321.4 | 324.4 |

| Annual Index: |
|---|
| 2006 = 499.6 |
| 2007 = 525.4 |
| 2008 = 575.4 |
| 2009 = 521.9 |
| 2010 = 550.8 |
| 2011 = 585.7 |
| 2012 = 584.6 |
| 2013 = 567.3 |

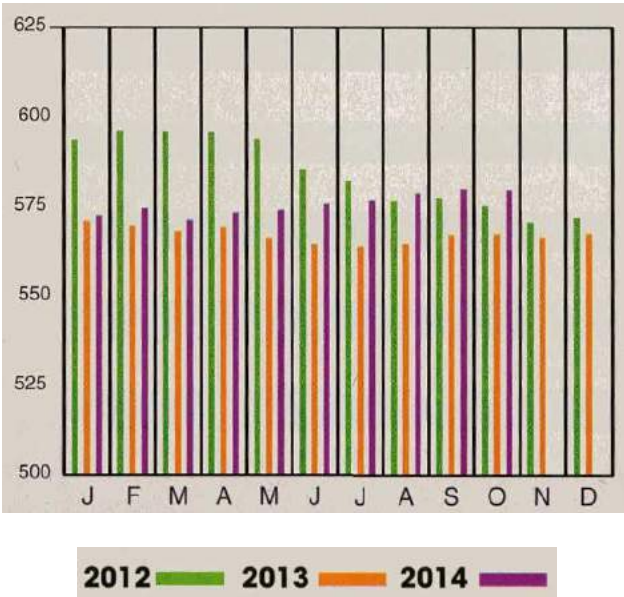



**Figure A 1.1: Annual cost index for year 2013 and 2014**

**Table A 1.2 CEPCI for year 2015 and 2016**

| CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI) (1957-59=100) | | Jan’16 Prelim. | Dec’15 Final | Jan’15 Final |
|---|---|---|---|---|
| CE Index | | 536.5 | 537.0 | 573.1 |
| Equipment | | 640.5 | 641.1 | 694.8 |
| a. | Heat exchangers & tanks | 551.7 | 556.0 | 636.4 |
| b. | Process machinery | 648.5 | 649.2 | 663.5 |
| c. | Pipes, valves & fittings | 795.0 | 791.3 | 868.9 |
| d. | Process instruments | 379.0 | 381.2 | 407.2 |
| e. | Pumps & compressors | 979.1 | 965.0 | 948.7 |
| f. | Electrical equipment | 509.0 | 507.7 | 513.9 |
| g. | Structural supports & misc | 701.9 | 703.0 | 758.0 |
| Construction labor | | 320.2 | 321.6 | 321.5 |
| Buildings | | 537.8 | 536.6 | 546.9 |
| Engineering & supervision | | 317.7 | 316.2 | 320.1 |

| **Annual Index:** |
|---|
| 2008 = 575.4 |
| 2009 = 521.9 |
| 2010 = 550.8 |
| 2011 = 585.7 |
| 2012 = 584.6 |
| 2013 = 567.3 |
| 2014 = 576.1 |
| 2015 = 556.8 |

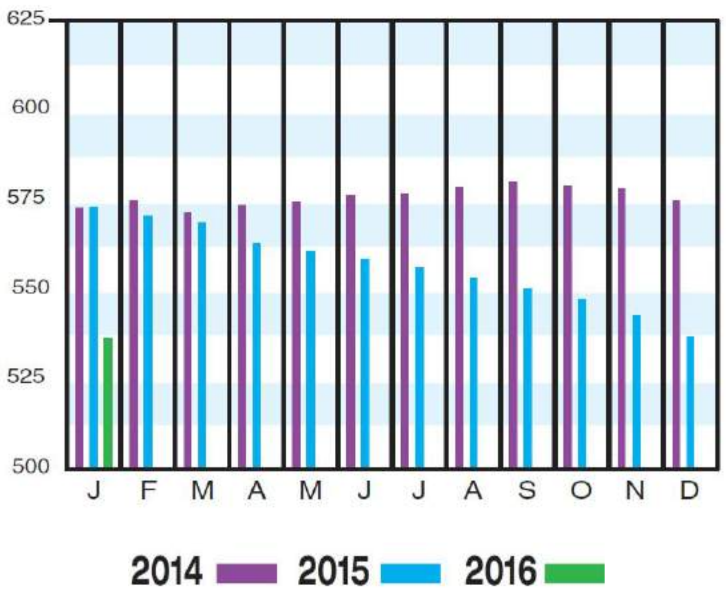



**Table A 1.2: Annual cost index for year 2015 and 2016**

# APPENDIX 2

## A2.1 CAPITAL COST ESTIMATION REPORT FOR PSA UNIT

3.00

PROJECT:

C O N T R A C T   S U M M A R Y

PRIME CONTRACTOR   (CONTRACT NO. 1)

| NO. | ITEM | DESIGN ENG'G AND PROCUREMENT K-USD | CONSTRUCTION: MATERIAL K-USD | MANHOURS | MANPOWER K-USD | INDIRECTS K-USD | MISC. AND ALL SUBCONTRACTS * K-USD | AMOUNT K-USD | PERCENT OF CONTRACT TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| 1 | PURCHASED EQUIPMENT | - | 119.4 | - | - | - | - | 119.4 | 4.3 |
| 2 | EQUIPMENT SETTING | - | - | 393. | 12.2 | - | - | 12.2 | 0.4 |
| 3 | PIPING | - | 41.5 | 1386. | 41.9 | - | - | 83.4 | 3.0 |
| 4 | CIVIL | - | 52.5 | 1502. | 36.6 | - | - | 89.1 | 3.2 |
| 5 | STEEL | - | 34.7 | 231. | 6.4 | - | - | 41.1 | 1.5 |
| 6 | INSTRUMENTATION | - | 266.4 | 746. | 22.8 | - | - | 289.2 | 10.4 |
| 7 | ELECTRICAL | - | 430.3 | 2243. | 65.3 | - | - | 495.6 | 17.9 |
| 8 | INSULATION | - | 0.0 | 0. | 0.0 | - | - | 0.0 | 0.0 |
| 9 | PAINT | - | 6.5 | 621. | 13.9 | - | - | 20.4 | 0.7 |
| 10 | OTHER | 929.8 | 97.5 | - | 0.0 | 377.2 | - | 1404.5 | 50.6 |
| 11 | SUBTOTAL | 929.8 | 1048.7 | 7124. | 199.1 | 377.2 | - | 2554.9 | 92.1 |
| 12 | SUBCONTRACTS | - | - | | - | - | 0.0 | 0.0 | 0.0 |
| 13 | G AND A OVERHEADS | 0.0 | 31.5 | | 6.0 | 11.3 | 0.0 | 48.8 | 1.8 |
| 14 | CONTRACT FEE | 72.5 | 34.6 | | 21.7 | 41.2 | 0.0 | 170.0 | 6.1 |
| 15 | BASE TOTAL | 1002.3 | 1114.8 | | 226.8 | 429.7 | 0.0 | 2773.6 | 100.0 |
| 16 | CONTINGENCIES | 180.4 | 200.7 | | 40.8 | 77.3 | 0.0 | 499.3 | 18.0 |
| 17 | TOTAL | 1182.7 | 1315.4 | | 267.7 | 507.0 | 0.0 | 3272.9 | 118.0 |

* NO SUBCONTRACTS

**Figure A 2.1: Contract Summary of PSA Project**

PROJECT:

CODE OF ACCOUNTS SUMMARY - CONTRACT NO. 1 PRIME CONTRACTOR

| CODE | ALLOC | DESCRIPTION | MATERIAL COST USD | MANPOWER MANHOURS | MANPOWER COST USD |
|---|---|---|---|---|---|
| 100 | EQ | EQUIPMENT AND SETTING | 0 | 0 | 0 |
| 105 | EQ | MISC. ITEM ALLOWANCE | 3500 | 0 | 0 |
| 112 | EQ | PACKED TOWERS & PACKING | 52900 | 282 | 8746 |
| 113 | EQ | VERTICAL VESSELS | 13400 | 50 | 1550 |
| 121 | EQ | ATMOSPHERIC STORAGE TANK | 49600 | 61 | 1894 |
| 200 | EQ | FLUID SEPARATION EQUIP. | 0 | 0 | 0 |
| | | SUBTOTAL ( 100- 293) | 119400 | 393 | 12190 |
| 300 | P | PIPING | 0 | 0 | 0 |
| 306 | P | PIPING SYSTEM TESTING | 0 | 106 | 3103 |
| 307 | P | PREFAB PIPE REWORK | 0 | 28 | 826 |
| 311 | P | CS FIELD MATERIAL | 4608 | 0 | 0 |
| 312 | P | CS FIELD SHOP FAB | 0 | 251 | 7759 |
| 313 | P | CS REMOTE SHOP MATERIAL | 5696 | 0 | 0 |
| 314 | P | CS REMOTE SHOP FAB | 14676 | 0 | 0 |
| 315 | P | CS VALVES: FLANGED | 11376 | 0 | 0 |
| 316 | P | CS VALVES: NON-FLANGED | 1311 | 0 | 0 |
| 317 | P | CS PIPE ERECTION | 0 | 826 | 25014 |
| 366 | P | PIPE HANGERS, SHOES ETC. | 3872 | 176 | 5203 |
| | | SUBTOTAL ( 300- 399) | 41540 | 1386 | 41904 |
| 400 | C | CIVIL | 0 | 0 | 0 |
| 436 | C | PILING | 23043 | 211 | 5641 |
| 444 | C | POURED CONCRETE | 13202 | 0 | 0 |
| 445 | C | GROUT | 2517 | 116 | 2681 |
| 446 | C | CONCRETE POUR AND FINISH | 328 | 337 | 7466 |
| 447 | C | EXCAVATION | 0 | 46 | 946 |
| 451 | C | REBAR | 7968 | 237 | 6791 |
| 452 | C | FOUNDATION ACCESSORIES | 3738 | 105 | 2595 |
| 454 | C | FORMWORK MATERIALS | 1699 | 0 | 0 |
| 456 | C | INSTALL FORMWORK | 0 | 362 | 8455 |
| 457 | C | STRIP & CLEAN FORMWORK | 0 | 83 | 1940 |
| 458 | C | BACKFILL | 0 | 5 | 95 |
| | | SUBTOTAL ( 400- 499) | 52496 | 1502 | 36610 |

**Figure A 2.2: a. Code of Accounts Summary Breakdown Page 1**

PROJECT:

CODE OF ACCOUNTS SUMMARY - CONTRACT NO. 1 PRIME CONTRACTOR

| CODE | ALLOC | DESCRIPTION | MATERIAL COST USD | MANPOWER MANHOURS | MANPOWER COST USD |
|---|---|---|---|---|---|
| 500 | ST | STEEL | 0 | 0 | 0 |
| 512 | ST | LADDERS | 7270 | 60 | 1708 |
| 513 | ST | PLATFORMS | 20452 | 106 | 3009 |
| 531 | ST | FLOORING & STAIR TREADS | 1833 | 34 | 893 |
| 532 | ST | HANDRAIL AND TOE PLATE | 5126 | 20 | 527 |
| 591 | ST | STEEL UNLOAD & HANDLING | 0 | 11 | 286 |
| | | SUBTOTAL ( 500- 593) | 34680 | 231 | 6424 |
| 600 | I | INSTRUMENTATION | 0 | 0 | 0 |
| 612 | I | LEVEL INSTRUMENTS | 7116 | 164 | 5234 |
| 613 | I | PRESSURE INSTRUMENTS | 2510 | 50 | 1596 |
| 614 | I | TEMPERATURE INSTRUMENTS | 3261 | 80 | 2483 |
| 622 | I | CONTROL CTR CONNECTIONS | 0 | 19 | 566 |
| 632 | I | INSTRUMENT PIPING | 9070 | 98 | 2919 |
| 633 | I | TERMINATIONS | 261 | 9 | 281 |
| 636 | I | INSTRUMENT SIGNAL WIRING | 77 | 3 | 79 |
| 637 | I | MULTI-COND. INSTR. WIRE | 132 | 3 | 79 |
| 641 | I | TRAYS & SUPPORT | 806 | 27 | 750 |
| 642 | I | CONDUIT & FITTINGS | 1280 | 100 | 2969 |
| 646 | I | ELEC. JUNCTION BOXES | 650 | 3 | 99 |
| 661 | I | CONTROLLER INTERFACES | 18687 | 40 | 1201 |
| 662 | I | INDIC./RECORD INTERFACES | 1744 | 0 | 0 |
| 664 | I | OPERATOR STATIONS | 198644 | 80 | 2408 |
| 665 | I | CABLE/DATA HIGHWAYS | 2272 | 27 | 790 |
| 666 | I | BARRIERS & TRANSDUCERS | 1431 | 0 | 0 |
| 682 | I | SAFETY VALVES | 15747 | 0 | 0 |
| 685 | I | REGULATING VALVES | 2711 | 0 | 0 |
| 691 | I | INSTRUMENT TESTING | 0 | 43 | 1323 |
| | | SUBTOTAL ( 600- 691) | 266398 | 746 | 22777 |
| 700 | E | ELECTRICAL | 0 | 0 | 0 |
| 711 | E | WIRE/CABLE - LV | 1146 | 19 | 541 |
| 712 | E | WIRE/CABLE - HV | 9136 | 74 | 2161 |
| 715 | E | TERMINATORS/CONNECTORS | 2359 | 61 | 1789 |
| 721 | E | CONDUIT | 8685 | 310 | 9187 |
| 722 | E | CONDUIT FITTINGS | 3781 | 148 | 4391 |

**Figure A 2.2: b. Code of Accounts Summary Breakdown Page 2**

PROJECT:

CODE OF ACCOUNTS SUMMARY - CONTRACT NO. 1 PRIME CONTRACTOR

| CODE | ALLOC. | DESCRIPTION | MATERIAL COST USD | MANPOWER MANHOURS | MANPOWER COST USD |
|---|---|---|---|---|---|
| 733 | E | MOTOR CONTROL CENTER-LV | 9858 | 64 | 1918 |
| 737 | E | SWITCHGEAR - LV | 44320 | 225 | 6754 |
| 738 | E | BUS DUCT - LV | 13700 | 20 | 606 |
| 739 | E | DISCONNECT SWITCH | 8840 | 39 | 1107 |
| 741 | E | TRANSFORMERS - HV | 60032 | 88 | 2577 |
| 742 | E | SWITCHGEAR - HV | 181285 | 150 | 4503 |
| 743 | E | MCC EQUIPPED SPACE | 3377 | 0 | 0 |
| 745 | E | BUS DUCT - MV/HV | 20448 | 43 | 1279 |
| 747 | E | SUBSTATION STEEL | 25092 | 214 | 6311 |
| 752 | E | LIGHTING FIXTURES | 16753 | 124 | 3630 |
| 753 | E | RECEPTACLES/SWITCHES | 4943 | 24 | 715 |
| 755 | E | MISC. SMALL TRANSFORMERS | 6419 | 52 | 1530 |
| 756 | E | PANELBOARDS | 817 | 13 | 387 |
| 757 | E | WIRE/CABLE - LIGHTING | 335 | 13 | 367 |
| 761 | E | ELECTRICAL TRENCHING | 2156 | 79 | 1775 |
| 771 | E | GROUNDING SYSTEMS | 6776 | 402 | 11311 |
| 791 | E | ELECTRICAL CIRCUIT TSTNG | 0 | 83 | 2470 |
| | | SUBTOTAL ( 700- 797) | 430257 | 2243 | 65308 |
| 800 | IN | INSULATION, FIREPROOFING | 0 | 0 | 0 |
| 900 | PT | PAINT | 0 | 0 | 0 |
| 911 | PT | PAINT - EQUIPMENT | 2389 | 113 | 2500 |
| 912 | PT | PAINT - PIPING | 3162 | 258 | 5678 |
| 913 | PT | PAINT - STRUCTURES | 740 | 44 | 973 |
| 921 | PT | SURFACE PREP - EQUIPMENT | 98 | 126 | 2937 |
| 922 | PT | SURFACE PREP - PIPING | 86 | 73 | 1703 |
| 923 | PT | SURFACE PREP - STEEL | 0 | 6 | 123 |
| | | SUBTOTAL ( 900- 923) | 6475 | 621 | 13914 |

**Figure A 2.2: c. Code of Accounts Summary Breakdown Page 3**

PROJECT:

INDIRECTS AND ENGINEERING COST BREAKDOWN
CONTRACT NO. 1 PRIME CONTRACTOR

| CODE | ITEM | AMOUNT USD |
|---|---|---|
| FIELD & SPECIAL INDIRECTS: | | |
| 11 | FRINGE BENEFITS | 41800. |
| 12 | BURDENS | 47800. |
| 13 | CONSUMABLES, SMALL TOOLS | 6000. |
| 14 | MISC. (INSURANCE, ETC) | 15000. |
| 15 | SCAFFOLDING, PLATFORMS | 6000. |
| 16 | EQUIPMENT RENTAL | 75500. |
| 18 | FIELD SERVICES | 14400. |
| 19 | TEMP. CONST., UTILITIES | 3200. |
| SUBTOTAL | | 209700. |
| FREIGHT: | | |
| 55 | OTHER FREIGHT | 38000. |
| SUBTOTAL | | 38000. |
| ENGINEERING: | | |
| 71 | BASIC ENGINEERING | 259700. |
| 72 | DETAIL ENGINEERING | 480400. |
| 73 | MATERIAL PROCUREMENT | 146200. |
| SUBTOTAL | | 886300. |
| ENGINEERING INDIRECTS: | | |
| 81 | HOME OFFICE CONST. SUPP. | 43500. |
| SUBTOTAL | | 43500. |
| CONTRACTOR INDIRECTS: | | |
| 85 | FIELD CONST. SUPERVISION | 148500. |
| 86 | START-UP, COMMISSIONING | 19000. |
| SUBTOTAL | | 167500. |
| OTHER PROJECT COSTS: | | |
| 90 | G AND A OVERHEADS | 48752. |
| 91 | CONTRACT FEE | 170014. |
| SUBTOTAL | | 218766. |

**Figure A 2.3: Indirect and Engineering Cost Breakdown**

# A2.2 CAPITAL COST ESTIMATION REPORT FOR PDU

3.00

PROJECT:

C O N T R A C T   S U M M A R Y

PRIME CONTRACTOR (CONTRACT NO. 1)

| NO. | ITEM | DESIGN ENG'G AND PROCUREMENT K-USD | CONSTRUCTION MATERIAL K-USD | CONSTRUCTION MANHOURS | CONSTRUCTION MANPOWER K-USD | CONSTRUCTION INDIRECTS K-USD | MISC. AND ALL SUBCONTRACTS * K-USD | AMOUNT K-USD | PERCENT OF CONTRACT TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| 1 | PURCHASED EQUIPMENT | - | 267.7 | - | - | - | - | 267.7 | 6.9 |
| 2 | EQUIPMENT SETTING | - | - | 1095. | 33.8 | - | - | 33.8 | 0.9 |
| 3 | PIPING | - | 84.1 | 2845. | 86.1 | - | - | 170.2 | 4.4 |
| 4 | CIVIL | - | 38.9 | 1851. | 44.9 | - | - | 83.8 | 2.2 |
| 5 | STEEL | - | 20.2 | 122. | 3.4 | - | - | 23.6 | 0.6 |
| 6 | INSTRUMENTATION | - | 394.8 | 2069. | 63.3 | - | - | 458.1 | 11.8 |
| 7 | ELECTRICAL | - | 563.4 | 2959. | 86.6 | - | - | 650.0 | 16.7 |
| 8 | INSULATION | - | 8.3 | 318. | 7.3 | - | - | 15.6 | 0.4 |
| 9 | PAINT | - | 5.6 | 583. | 13.0 | - | - | 18.6 | 0.5 |
| 10 | OTHER | 1220.1 | 141.7 | - | 0.0 | 514.1 | - | 1875.9 | 48.3 |
| 11 | SUBTOTAL | 1220.1 | 1524.7 | 11843. | 338.4 | 514.1 | - | 3597.3 | 92.5 |
| 12 | SUBCONTRACTS | - | - | | - | - | 0.0 | 0.0 | 0.0 |
| 13 | G AND A OVERHEADS | 0.0 | 45.7 | | 10.2 | 15.4 | 0.0 | 71.3 | 1.8 |
| 14 | CONTRACT FEE | 89.1 | 40.8 | | 35.2 | 53.5 | 0.0 | 218.6 | 5.6 |
| 15 | BASE TOTAL | 1309.2 | 1611.2 | | 383.8 | 583.0 | 0.0 | 3887.2 | 100.0 |
| 16 | CONTINGENCIES | 235.7 | 290.0 | | 69.1 | 104.9 | 0.0 | 699.7 | 18.0 |
| 17 | TOTAL | 1544.8 | 1901.3 | | 452.8 | 687.9 | 0.0 | 4586.9 | 118.0 |

* NO SUBCONTRACTS

**Figure A 2.4: Contract Summary of PDU Project**

PROJECT:

CODE OF ACCOUNTS SUMMARY - CONTRACT NO. 1 PRIME CONTRACTOR

| CODE | ALLOC | DESCRIPTION | MATERIAL COST USD | MANPOWER MANHOURS | MANPOWER COST USD |
|---|---|---|---|---|---|
| 100 | EQ | EQUIPMENT AND SETTING | 0 | 0 | 0 |
| 105 | EQ | MISC. ITEM ALLOWANCE | 7700 | 0 | 0 |
| 107 | EQ | WAREHOUSE SPARES | 5500 | 0 | 0 |
| 112 | EQ | PACKED TOWERS & PACKING | 40600 | 120 | 3708 |
| 113 | EQ | VERTICAL VESSELS | 2300 | 25 | 775 |
| 134 | EQ | MIXERS | 102600 | 604 | 18718 |
| 151 | EQ | CENTRIFUGAL COMPRESSORS | 77400 | 173 | 5320 |
| 192 | EQ | FILTERS | 9600 | 72 | 2218 |
| 200 | EQ | FLUID SEPARATION EQUIP. | 0 | 0 | 0 |
| 261 | EQ | SHELL & TUBE EXCHANGERS | 16300 | 76 | 2245 |
| 266 | EQ | MISC. HEAT EXCHANGERS | 5700 | 26 | 805 |
| | | SUBTOTAL ( 100- 293) | 267700 | 1095 | 33788 |
| 300 | P | PIPING | 0 | 0 | 0 |
| 305 | P | OTHER EQUIPMENT PIPE | 12658 | 141 | 4231 |
| 306 | P | PIPING SYSTEM TESTING | 0 | 214 | 6262 |
| 307 | P | PREFAB PIPE REWORK | 0 | 50 | 1484 |
| 311 | P | CS FIELD MATERIAL | 10512 | 0 | 0 |
| 312 | P | CS FIELD SHOP FAB | 0 | 499 | 15446 |
| 313 | P | CS REMOTE SHOP MATERIAL | 9676 | 0 | 0 |
| 314 | P | CS REMOTE SHOP FAB | 26371 | 0 | 0 |
| 315 | P | CS VALVES: FLANGED | 15349 | 0 | 0 |
| 316 | P | CS VALVES: NON-FLANGED | 2873 | 0 | 0 |
| 317 | P | CS PIPE ERECTION | 0 | 1611 | 48901 |
| 366 | P | PIPE HANGERS, SHOES ETC. | 6610 | 330 | 9789 |
| | | SUBTOTAL ( 300- 399) | 84050 | 2845 | 86113 |
| 400 | C | CIVIL | 0 | 0 | 0 |
| 436 | C | PILING | 8863 | 131 | 3484 |
| 444 | C | POURED CONCRETE | 6095 | 0 | 0 |
| 445 | C | GROUT | 748 | 39 | 897 |
| 446 | C | CONCRETE POUR AND FINISH | 137 | 173 | 3839 |
| 447 | C | EXCAVATION | 0 | 28 | 584 |
| 449 | C | OTHER EQUIP. CONCRETE | 16475 | 1026 | 24726 |

**Figure A 2.5: a. Code of Accounts Summary Breakdown Page 1**

PROJECT:

CODE OF ACCOUNTS SUMMARY - CONTRACT NO. 1 PRIME CONTRACTOR

| CODE | ALLOC | DESCRIPTION | MATERIAL COST USD | MANPOWER MANHOURS | MANPOWER COST USD |
|---|---|---|---|---|---|
| 451 | C | REBAR | 4179 | 146 | 4193 |
| 452 | C | FOUNDATION ACCESSORIES | 1343 | 40 | 960 |
| 454 | C | FORMWORK MATERIALS | 1063 | 0 | 0 |
| 456 | C | INSTALL FORMWORK | 0 | 220 | 5149 |
| 457 | C | STRIP & CLEAN FORMWORK | 0 | 43 | 1013 |
| 458 | C | BACKFILL | 0 | 4 | 69 |
| | | SUBTOTAL ( 400- 499) | 38902 | 1851 | 44933 |
| 500 | ST | STEEL | 0 | 0 | 0 |
| 512 | ST | LADDERS | 3623 | 30 | 852 |
| 513 | ST | PLATFORMS | 16537 | 86 | 2433 |
| 591 | ST | STEEL UNLOAD & HANDLING | 0 | 6 | 150 |
| | | SUBTOTAL ( 500- 593) | 20160 | 122 | 3435 |
| 600 | I | INSTRUMENTATION | 0 | 0 | 0 |
| 611 | I | FLOW INSTRUMENTS | 1144 | 18 | 574 |
| 612 | I | LEVEL INSTRUMENTS | 3558 | 65 | 2075 |
| 613 | I | PRESSURE INSTRUMENTS | 10673 | 215 | 6862 |
| 614 | I | TEMPERATURE INSTRUMENTS | 17323 | 401 | 12566 |
| 616 | I | MOTION INSTRUMENTS | 2666 | 27 | 841 |
| 618 | I | ORIFICE PLATES | 255 | 0 | 0 |
| 619 | I | OTHER EQUIPMENT INSTR. | 5273 | 53 | 1634 |
| 622 | I | CONTROL CTR CONNECTIONS | 0 | 113 | 3407 |
| 627 | I | EQUIP. CONTROL PANEL | 7843 | 30 | 957 |
| 628 | I | EQUIP. PANEL DEVICES | 14981 | 39 | 1163 |
| 631 | I | AIR SUPPLY PIPING | 1565 | 73 | 2150 |
| 632 | I | INSTRUMENT PIPING | 10564 | 159 | 4867 |
| 633 | I | TERMINATIONS | 1567 | 59 | 1773 |
| 634 | I | PNEUMATIC TUBING | 40 | 11 | 353 |
| 636 | I | INSTRUMENT SIGNAL WIRING | 510 | 18 | 527 |
| 637 | I | MULTI-COND. INSTR. WIRE | 608 | 8 | 226 |
| 641 | I | TRAYS & SUPPORT | 806 | 27 | 750 |
| 642 | I | CONDUIT & FITTINGS | 5792 | 463 | 13735 |
| 646 | I | ELEC. JUNCTION BOXES | 1057 | 11 | 334 |
| 653 | I | SOLENOIDS | 534 | 11 | 340 |
| 659 | I | OTHER INSTR. ELECTRICAL | 3235 | 0 | 0 |

**Figure A 2.5: b. Code of Accounts Summary Breakdown Page 2**

PROJECT:

CODE OF ACCOUNTS SUMMARY - CONTRACT NO. 1 PRIME CONTRACTOR

| CODE | ALLOC | DESCRIPTION | MATERIAL COST USD | MANPOWER MANHOURS | MANPOWER COST USD |
|---|---|---|---|---|---|
| 661 | I | CONTROLLER INTERFACES | 48462 | 20 | 600 |
| 662 | I | INDIC./RECORD INTERFACES | 8721 | 0 | 0 |
| 664 | I | OPERATOR STATIONS | 198644 | 80 | 2408 |
| 665 | I | CABLE/DATA HIGHWAYS | 2272 | 27 | 790 |
| 666 | I | BARRIERS & TRANSDUCERS | 6878 | 0 | 0 |
| 669 | I | OTHER COMPUTER CONTROL | 4610 | 0 | 0 |
| 681 | I | CONTROL VALVES | 25950 | 0 | 0 |
| 682 | I | SAFETY VALVES | 9282 | 0 | 0 |
| 691 | I | INSTRUMENT TESTING | 0 | 141 | 4337 |
| | | SUBTOTAL ( 600- 691) | 394813 | 2069 | 63289 |
| 700 | E | ELECTRICAL | 0 | 0 | 0 |
| 711 | E | WIRE/CABLE - LV | 1474 | 29 | 851 |
| 712 | E | WIRE/CABLE - HV | 9136 | 74 | 2161 |
| 714 | E | PUSH BUTTON STATION | 3427 | 63 | 1888 |
| 715 | E | TERMINATORS/CONNECTORS | 3889 | 114 | 3322 |
| 717 | E | WIRE/CABLE - MV | 112 | 1 | 36 |
| 718 | E | WIRE/CABLE - CV | 706 | 26 | 759 |
| 721 | E | CONDUIT | 10643 | 467 | 13865 |
| 722 | E | CONDUIT FITTINGS | 4430 | 204 | 6063 |
| 733 | E | MOTOR CONTROL CENTER-LV | 22161 | 132 | 3955 |
| 736 | E | SWITCHGEAR - MV | 83811 | 150 | 4503 |
| 737 | E | SWITCHGEAR - LV | 44320 | 225 | 6754 |
| 738 | E | BUS DUCT - LV | 13700 | 20 | 606 |
| 739 | E | DISCONNECT SWITCH | 8840 | 39 | 1107 |
| 741 | E | TRANSFORMERS - HV | 72733 | 201 | 5903 |
| 742 | E | SWITCHGEAR - HV | 181285 | 150 | 4503 |
| 743 | E | MCC EQUIPPED SPACE | 3001 | 0 | 0 |
| 745 | E | BUS DUCT - MV/HV | 39332 | 83 | 2476 |
| 747 | E | SUBSTATION STEEL | 25092 | 214 | 6311 |
| 752 | E | LIGHTING FIXTURES | 13613 | 87 | 2540 |
| 753 | E | RECEPTACLES/SWITCHES | 4943 | 24 | 715 |
| 755 | E | MISC. SMALL TRANSFORMERS | 6419 | 52 | 1530 |
| 756 | E | PANELBOARDS | 817 | 13 | 387 |
| 757 | E | WIRE/CABLE - LIGHTING | 265 | 10 | 290 |
| 761 | E | ELECTRICAL TRENCHING | 2156 | 79 | 1775 |
| 771 | E | GROUNDING SYSTEMS | 7097 | 418 | 11764 |
| 791 | E | ELECTRICAL CIRCUIT TSTNG | 0 | 84 | 2509 |

**Figure A 2.5: c. Code of Accounts Summary Breakdown Page 3**

PROJECT:

CODE OF ACCOUNTS SUMMARY - CONTRACT NO. 1 PRIME CONTRACTOR

| CODE | ALLOC | DESCRIPTION | MATERIAL COST USD | MANPOWER MANHOURS | MANPOWER COST USD |
|---|---|---|---|---|---|
| | | SUBTOTAL ( 700- 797) | 563402 | 2959 | 86572 |
| 800 | IN | INSULATION, FIREPROOFING | 0 | 0 | 0 |
| 811 | IN | PIPE INSULATION | 7327 | 248 | 5669 |
| 812 | IN | EQUIP INSULATION | 1020 | 70 | 1594 |
| | | SUBTOTAL ( 800- 831) | 8347 | 318 | 7263 |
| 900 | PT | PAINT | 0 | 0 | 0 |
| 911 | PT | PAINT - EQUIPMENT | 280 | 18 | 392 |
| 912 | PT | PAINT - PIPING | 4763 | 396 | 8724 |
| 913 | PT | PAINT - STRUCTURES | 388 | 23 | 517 |
| 921 | PT | SURFACE PREP - EQUIPMENT | 0 | 2 | 48 |
| 922 | PT | SURFACE PREP - PIPING | 164 | 140 | 3269 |
| 923 | PT | SURFACE PREP - STEEL | 0 | 3 | 65 |
| | | SUBTOTAL ( 900- 923) | 5595 | 583 | 13015 |

**Figure A 2.5: d. Code of Accounts Summary Breakdown Page 4**

PROJECT:

INDIRECTS AND ENGINEERING COST BREAKDOWN
CONTRACT NO. 1 FRIME CONTRACTOR

| CODE | I T E M | AMOUNT USD |
|---|---|---|
| FIELD & SPECIAL INDIRECTS: | | |
| 11 | FRINGE BENEFITS | 71100. |
| 12 | BURDENS | 81200. |
| 13 | CONSUMABLES, SMALL TOOLS | 10200. |
| 14 | MISC. (INSURANCE, ETC) | 25500. |
| 15 | SCAFFOLDING, PLATFORMS | 10200. |
| 16 | EQUIPMENT RENTAL | 63500. |
| 18 | FIELD SERVICES | 23900. |
| 19 | TEMP. CONST., UTILITIES | 5300. |
| SUBTOTAL | | 290900. |
| FREIGHT: | | |
| 55 | OTHER FREIGHT | 55300. |
| SUBTOTAL | | 55300. |
| ENGINEERING: | | |
| 71 | BASIC ENGINEERING | 320200. |
| 72 | DETAIL ENGINEERING | 610600. |
| 73 | MATERIAL PROCUREMENT | 240100. |
| SUBTOTAL | | 1170900. |
| ENGINEERING INDIRECTS: | | |
| 81 | HOME OFFICE CONST. SUPP. | 49200. |
| SUBTOTAL | | 49200. |
| CONTRACTOR INDIRECTS: | | |
| 85 | FIELD CONST. SUPERVISION | 193600. |
| 86 | START-UP, COMMISSIONING | 29600. |
| SUBTOTAL | | 223200. |
| OTHER PROJECT COSTS: | | |
| 90 | G AND A OVERHEADS | 71315. |
| 91 | CONTRACT FEE | 218584. |
| SUBTOTAL | | 289899. |

**Figure A 2.6: Indirect and Engineering Cost Breakdown**

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