CAREER EPISODE 2

CE 2.1 Introduction

In this episode of my career, I shall discuss the elaborate details of the work that I performed for one of my academic projects during my Chemical Engineering bachelor degree program. I performed this project as the 6th semester project while I was studying at the [redacted]. This project began in ______ and was due to be submitted for evaluation on _____, providing me with approximately ____ months to complete. This was a group project in which each group consisted of

CE 2.2 Background

CE 2.2.1
The main motivation behind this project was to increase the domestic production of hydrogen in order to fulfil the vital agricultural & industrial needs by the means of a process which apart from being effective, efficient and economically viable is also energy efficient and climate friendly.

CE 2.2.2
I also undertook the designing process with my team in which we performed thorough computations which involved the vital process equipment design as well as cost analysis, instrumentation and control for process. We also completed HAZOP analysis along with all the prerequisites for the achievement of 97% purity of hydrogen.

CE 2.2.3
The major requirement of hydrogen in Pakistan is for agricultural sector as it is required in large volumes for producing urea which is important constituent of ammonia. So, another reason for accepting this project was to help my country in becoming self-sufficient for the production of fertilizer for domestic needs. The use of hydrogen as a substitute helps in reducing pollution as the only by products from the production of hydrogen are water and heat. There is a dire need to work on alternatives and processes using hydrogen as it will play an important role in the future.

CE 2.2.4
This project was a group task where each group was comprised of five members. I was selected as the group leader for this project and we worked under the project supervisor. The following diagram expresses the reporting hierarchy for this project:

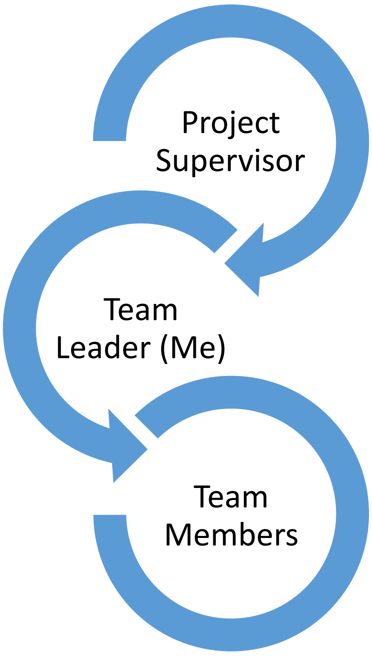

Fig. 2.1. Reporting Hierarchy for the project

CE 2.3 Personal Engineering Activity

CE 2.3.1

In the initial phase of this project, I carried out a commercial and market analysis for hydrogen production with respect to Pakistan. Hydrogen's main use is production of Ammonia. Another use for hydrogen that I learnt was its use in petroleum industry as feedstock for olefins and for desulphurization of petroleum products. Most of the hydrogen used in Pakistan is imported. It was also found by me that it is used in fuel cells which are replacing dry batteries. Hence this analysis helped us to identify the need and demand of hydrogen and also the need for alternative processes to decrease import bills and also to create positive impact on the environment.

CE 2.3.2

In this step we completed the process selection task. In this task, we evaluated different processes applicable for the production of hydrogen on commercial level. Upon further research I found out that the different process include production through biomass, steam reforming, and partial oxidation of hydrocarbons, coal gasification and electrolysis. I evaluated the merits and demerits of different processes by thoroughly studying them. I analysed them on the basis of feedstock used in different processes, their thermal efficiency, the by products produced and environmental impact caused by them. After considering all of the factors stated above, the process of steam reforming of refinery off gases in a reformer was selected. I selected this as one of the widely used methods for production of hydrogen. In this process, I defined that most of the hydrocarbons will be converted into carbon monoxide and hydrogen in the presence of catalyst. As the carbon monoxide produced maybe harmful to be exhausted in to the air without treatment, so it must be converted into carbon dioxide. For this purpose I suggested the use of shift converters. Another reason for selecting this process was that it had effective cost benefit as cheaper than most of the other processes. Also that it produces pure hydrogen gas. Another reason that I observed to justify this selection was that the raw materials mainly natural gas used in this process is low cost, which makes this process more desirable.

CE 2.3.3

In the next step, a suitable site had to be selected for the proposed plant. So after due deliberation with my team members and the project supervisor, the selected site was [redacted], [redacted], Pakistan. I selected this site as it was situated in the middle of National Refinery Limited and Pakistan Refinery Limited and it would be easier to obtain off gases from one of these plants for the process.

CE 2.3.4

In the next step of this project, I developed the process flow diagram. The following figure shows it and it helped us develop a better understanding of the entire process with all the steps included in it.

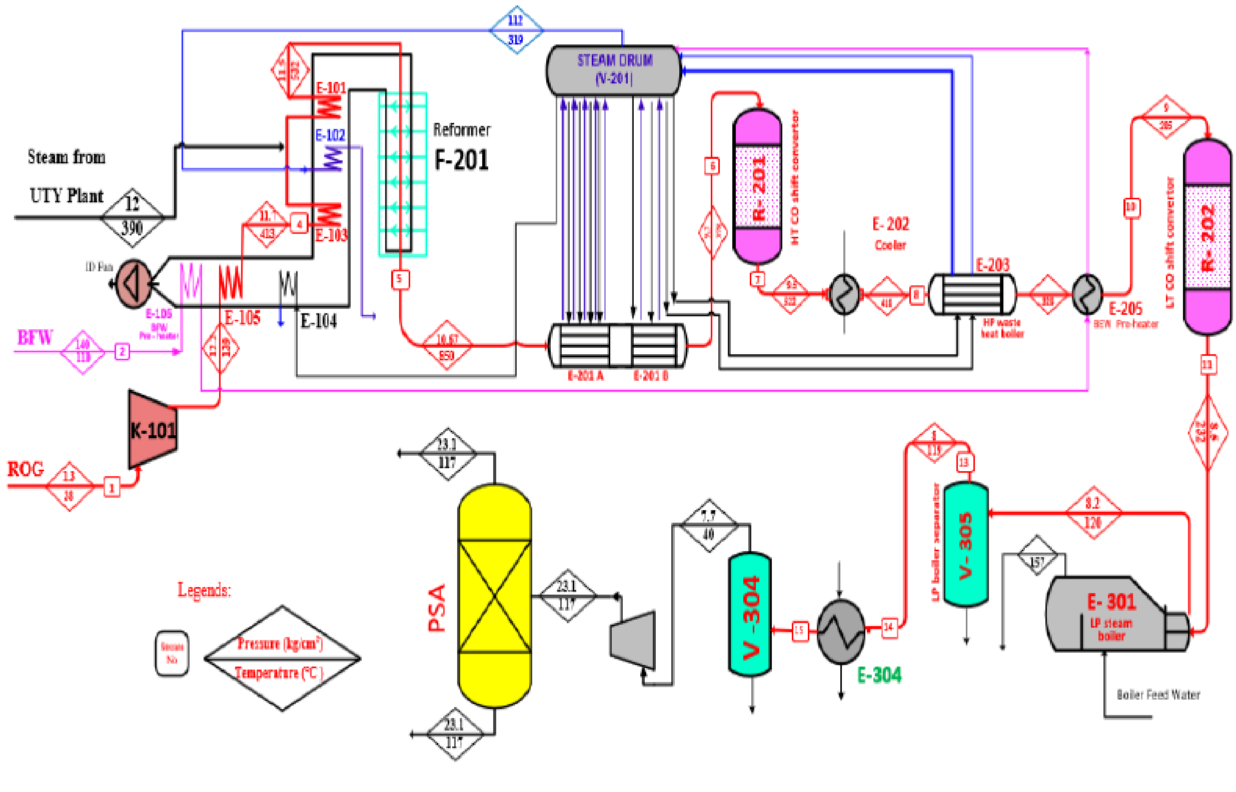

Fig. 2.2. Process Flow Diagram

CE 2.3.5

In the next step which is an important task that I carried out was the detailed computations of the material balance which play a vital role in such projects as ours. Feed for the Plant was coming from the Refinery so we called it Refinery Off Gases (ROG). We also use the steam coming from the utility, the feed flow rate and the steam condition were; basis = 1hr and Feed Flow rate = 2000 kgmol. I calculated the fraction of the carbon as follows:

Fraction of the Carbon = (1×0.85) + (2×0.0662) + (0.0172×3) + (0.0439×1) =1.0779

Whereas; the Steam to carbon ratio = $SteamC$ = 2.7

And Flow rate of the steam = 2.7 × 1.0779 × 2000 = 5820.66 $kgmol$

While; Total feed to the Plant: 2000 + 5820.66 = 7820.66 kgmol.

CE 2.3.6

Furthermore, after the completion of the material and energy balances, I played my part in the project by simulating the entire process using ASPEN HYSYS V10. For this analysis, at first I simulated each of the process component mentioned earlier and carried out the ASPEN analysis on each of them, the results are shown in the figure of the reformer below:

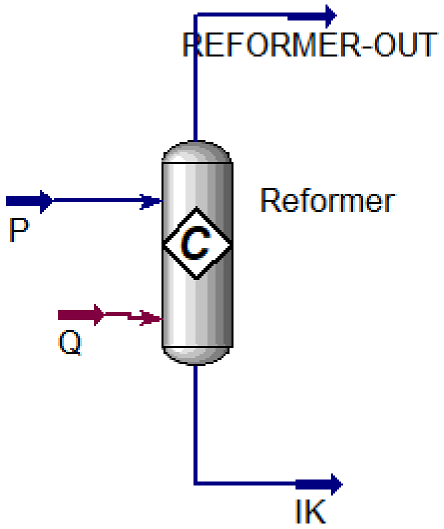

Fig. 2.3. Systematic Design for the Reformer

	REFORMER-IN	REFORMER-OUT	Ik
Methane	0.2174	0.0116	0.0116
Ethane	0.0169	0.0000	0.0000
Propane	0.0044	0.0000	0.0000
CO2	0.0112	0.0406	0.0406
CO	0.0000	0.1323	0.1323
Hydrogen	0.0022	0.5133	0.5133
H2O	0.7443	0.2998	0.2998
Nitrogen	0.0036	0.0024	0.0024

Fig. 2.4. Results of the Reformer Simulation

By the similar method, I simulated and analysed all different process components which included shift converter, knock-out vessels and swing adsorber which was followed by analysis of each component using the software.

CE 2.3.7

After this I carried out the energy balance computations on each of the component. The total enthalpy was calculated as follows:

Total Enthalpy Inlet = $\dot{m}Cp\Delta T$= (2000×38.335× (311.15-298.15)) = 996.71 MJ/hr

We have two compressors in series with the interstate cooling of the product of the first compressor and the product of the second is feed with the steam. The volumetric flow rate of the gases = 10.55 m3/sec so we use the centrifugal compressor of the operation. We select the efficiency of the compression is 75% with the compression ratio of 3.0.

CE 2.3.8

Using ASPEN Plus, I developed process flow sheet diagram which was simulated in the software and is shown below:

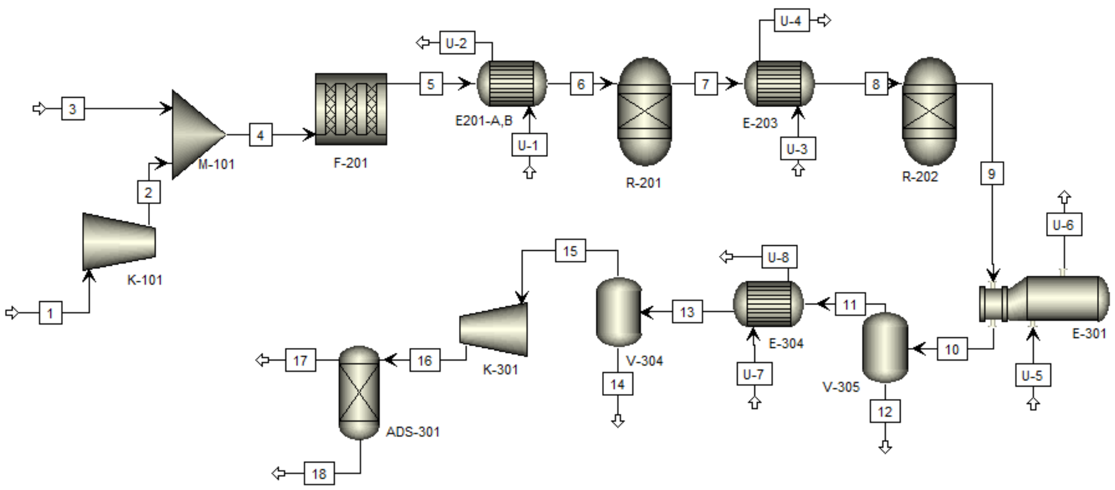

Fig. 2.5. Process Flow Sheet Diagram (Simulated on ASPEN PLUS®)

CE 2.3.9

In equipment design step, we in initially selected catalysts for the stem reforming process. There is a detailed scientific process for the selection of catalysts for the process on the basis of bearing of high temp conditions, retaining of thermodynamics properties, lifetime and resistance to change, environmental impact and cost after comparison of different catalysts. I found Ni to be more expensive but its use was preferred by me due to the reason that a very small percentage of this was needed in the process which compensates for the high price. Other reasons which I concluded were that Ni based catalyst could handle very high temperature ranges from 900-1100 C and it also shows good strength in mechanical terms.

CE 2.3.10

In the next step, I computed, pressure drop by using Ergun's equation which is the well-established engineering practice for the purpose of estimating pressure drop over the catalyst bed. It consisted of two parts, one having specifically for viscosity drop and other one was for superficial velocity drop. It also shows the dependence of Reynolds number that specify whether the flow was laminar as per Blake-Kozeny equation or turbulent as per Burke-Plummer equation.

CE 2.3.11

In the next phase of the project, I designed the reformer. The process of design included design reaction kinetics for the reaction, estimate the reforming type and reactor, identify the catalyst being used and its properties, estimate the weight of catalyst, find out the volume of catalyst and reactor, estimate the tube length and inner diameter, calculate the number of tubes required for required heat and reaction occurring, estimate the shell side calculations, find out the pressure drop calculated in this section. For the reaction kinetics, I followed Langmuir-Hinshelwood-Hogan-Watson Mechanism as per the equation below:

$$-rCH4=r1+r2$$

The weight of the catalyst was calculated as follows:

Fao = 1700 kmol/hr.

Xa = 0.92

Solving the integral on excel and finding by 3/8th Simpson's rule = 10.8664

Weight of catalyst (W) = 18472.88 kg

I computed the number of Tubes and Layout by the following equation:

$Q= n*3.14*ID*L*q_{avg}$

After the completion of all calculations, I summarized the design details in a table which was made using MS Word, shown below. Also I used TEMA specifications and standards for this entire design process.

Item Name	Steam Reformer (F-201)
Heat Required by Furnace	53775.09 kW
Reformer Type	Side Fired
Reactor type	Tubular
Volume of Reactor	32.65 m^3
Design Temperature	1123.15 K
Design Pressure	1046 kPa
Volume of catalyst	17.96 m^3
Volume of Voids	14.69 m^3
Weight of catalyst	18472.88 kg
Number of Tubes	240
Length of Tube	7 m
Inner Dia. of Tube	0.102 m
Bulk Density	1028.5 kg/ m3
Wall Thickness	0.0075 m
Material of Construction	Chromium Nickel Steel
Diameter of Particles	1.2 mm
Catalyst Density	1870 kg/m3
Bed Porosity	0.45
Shell Inner Diameter	2.93 m
Shell height	7.77 m
Square pitch	0.146 m
Shell Clearance	112.1 mm
Bundle Diameter	2.81 m
Pressure Drop	95.3kPa

Tab. 2.1. Design specifications summary

CE 2.3.12

In the next step my team designed heat exchanger low shift converter, kettle type re-boiler, pressure swing absorber along with the mechanical design (PSA) along with mechanical design by using TEMA standards which are a well-established engineering norm and practice.

CE 2.3.13

I also designed the process control mechanism by utilizing feed forward control system by using a temperature sensor known as the thermos couple. I used this because thermocouple senses the temperature of the product stream of ethanol reformer and converts it into electrical signal which was then transmitted to the comparator. The comparator then checks if the value of the temperature is greater than or less than 500°C and sends the error to the controller. In this way the controller then decides based on the error whether to open or to close the valve. I adjusted it in such a way that if the temperature of the outlet stream is less than 500°C, the controller will send the command to open the fuel valve slightly more so that the amount of fuel in the furnace is sufficient to meet the heat demand of the reaction and keep the temperature in the permissible limit.

CE 2.3.14

In the last step I carried out the HAZOP analysis which helped me to check and identify areas where hazards might occur, to carry out the study of the design features that can influence the probability of an incident causing hazardous effects, to check the available information related to the design aspect with study team, to ensure that areas of significant hazard potential can influence a systematic study, to search out new design information currently not available to the team and to provide a detailed methodology of the entire process.

CE 2.3.15

In the last step of the project, I carried out detailed project cost estimation for all aspects involved in this process. Initially, I computed cost index using the following formulas:

Present cost = original cost x ($cost\ index\ at\ present\ time\ cost\ index\ at\ original\ value\ time$)

Cost of equipment a = cost of equipment b *($capacity\ of\ equipment\ a$ / $capacity\ of\ equipment\ b)n$

Furthermore, I also calculated the fixed costs involved in this project which included the cost of heat exchanger, reformer and shift converter along with estimation of purchase of equipment cost and physical assembly cost which was computed using the values of typical factors for estimation of project fixed capital cost by making use of the provisions of the “Chemical Engineering Design, Coulson & Richardson’s Vol. 6, Table 6.1”. I also calculated the fixed capital cost by using the formula below:

FCC = PPC x (1 + f10 + f11 + f12) = PPC x (1.30)

FFC = $ 216258090

Then I calculated the working capital cost in which the allowed 5% of fixed capital was aimed to cover the initial fluid charge. The following equation was used by me:

WC = FCC x 0.05

WC = $ 10812905

The total Project Cost was calculated as:

PCC = FCC + WC

PCC = $ 32438795

CE 2.4 Summary

This project helped me to enhance my skills of interacting with different aspects of the project. During the time in which I worked at this project, I further learned presenting project activities in different ways while explaining to my team and as well as the project supervisor by submitting regular project reports. I found great improvement in my interpersonal skill. I learned the process simulation and software analysis as well. My project responsibility was involved in solving the tasks at hand step by step and also to keep plan updated for team to move with the same pace of the project. We successfully completed this project within the allocated period of time.