Design of a Naphtha Refinery

Sumaiya Ahmed, Jacob Martin, Jacob Vitale

Instructor: Dr. Chelsea Monty-Bromer

Department of Chemical and Biomedical Engineering, Washkewicz College of Engineering

Cleveland State University

Introduction

Oil is a blend of hydrocarbons whose naphtha fraction is distilled into gasoline and diesel fuels. Catalytic reforming reacts hazardous cyclic and polyaromatic hydrocarbons within naphtha into benzene, xylene, and toluene (BTX). This removes toxic feedstocks, especially benzene and polyaromatic hydrocarbons, as salable aromatics valued by the chemical industry.

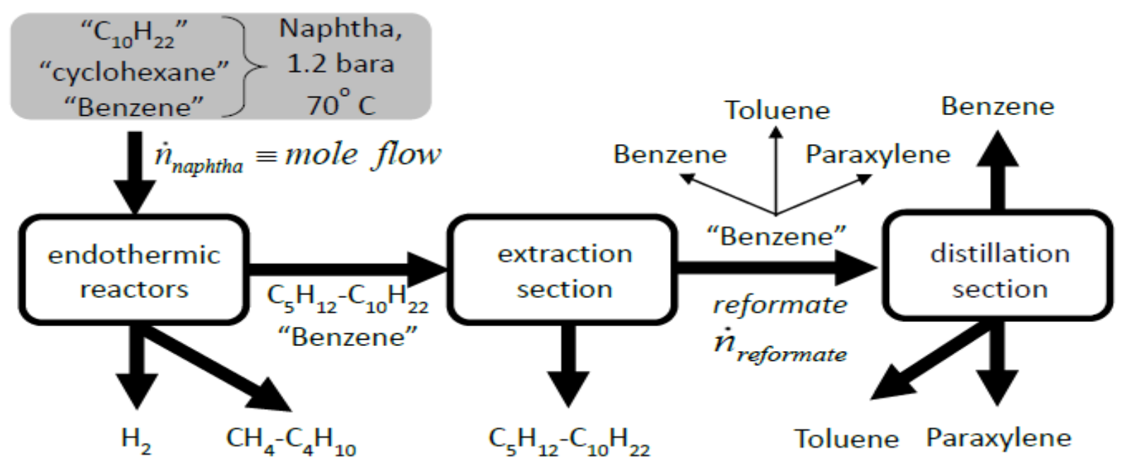


Image: *AICHE Project Description* [1]

Project Objective

- Design a process and study estimate which upgrades heavier naphtha into gasoline while providing BTX. This study is for an Iraqi oil refinery which produces 35,000 barrels per day.
- Technical Objectives: 1) BTX must have a 99% purity, 2) Environmental Health and Safety aspects must be considered, and 3) Inherently Safer Design strategies should be utilized
- Additional Safety Objectives: 1) Process Hazard Management, 2) P&ID of Major Fractionator, and 3) Uncongested Vapor Cloud Deflagration

Reactor

- Purpose: Process naphtha into linear alkanes (CH_4–$C_{10}H_{22}$) for fuel and industrial feedstocks (benzene, xylene, toluene)
- Reaction Modeling: $C_{10}H_{22}$ is used for all feed alkanes, C_6H_{12} is used all aromatics, C_6H_6 is used for all feedstocks
- Reactor Operation: L = 3 [m]; D = 1 [m]; T = 525 [°C]; P = 5 [bar]; $\rho_{catalyst}$ = 950 [kg/m³]; Particle Diameter = 3 [mm]; Void Fraction = 0.5 [unitless]
- Products: CH_4-C_4H_{10} (fuel, 189 kmol/hr), C_5H_{12} - C_8H_{18} (gasoline, 169.9 kmol/hr), C_9H_{20} (diesel, 42 kmol/hr), and C_6H_6 (feedstocks, 120 kmol/hr)

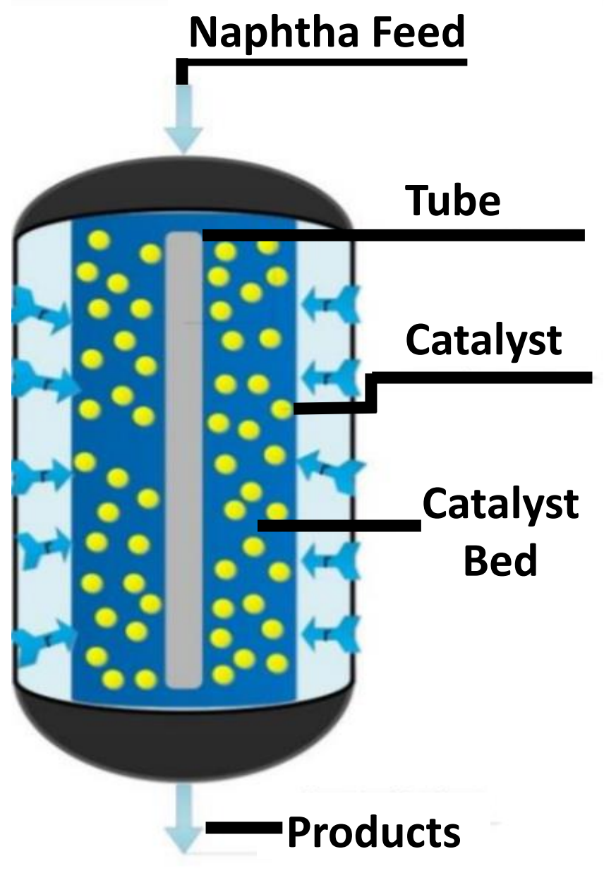


Image: *Journal of Chemical and Petroleum Engineering* [2]

Reactor

Extraction

Separations

Initial

BTX

Extraction

- Purpose: Isolate C_6H_6 from C_5H_{12} – $C_{10}H_{22}$. CH_4 – C_4H_{10} and H_2 are removed prior to the extraction unit.
- Operation: Stages = 105; T_{TOP} = 40 [°C]; P_{TOP} = 6.2 [bar]; T_{BOT} = -10 [°C]; P_{BOT} = 6.2 [bar];
- Sulfolane Solvent: Recycled to minimize costs (savings of $1.68 billion per year)
- Alkanes: 197.5 kmol/hr removed and 11.8 kmol/hr remain
- Additional separation is required to remove extra alkanes to obtain 99% purity specification

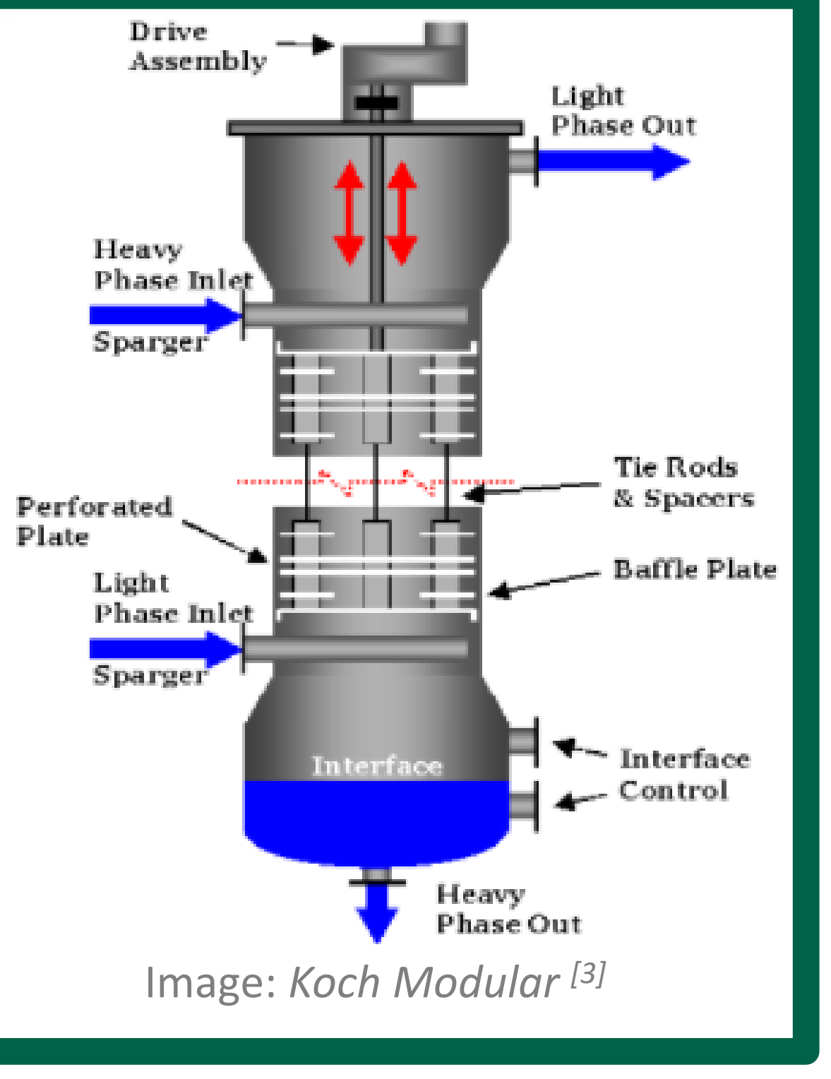
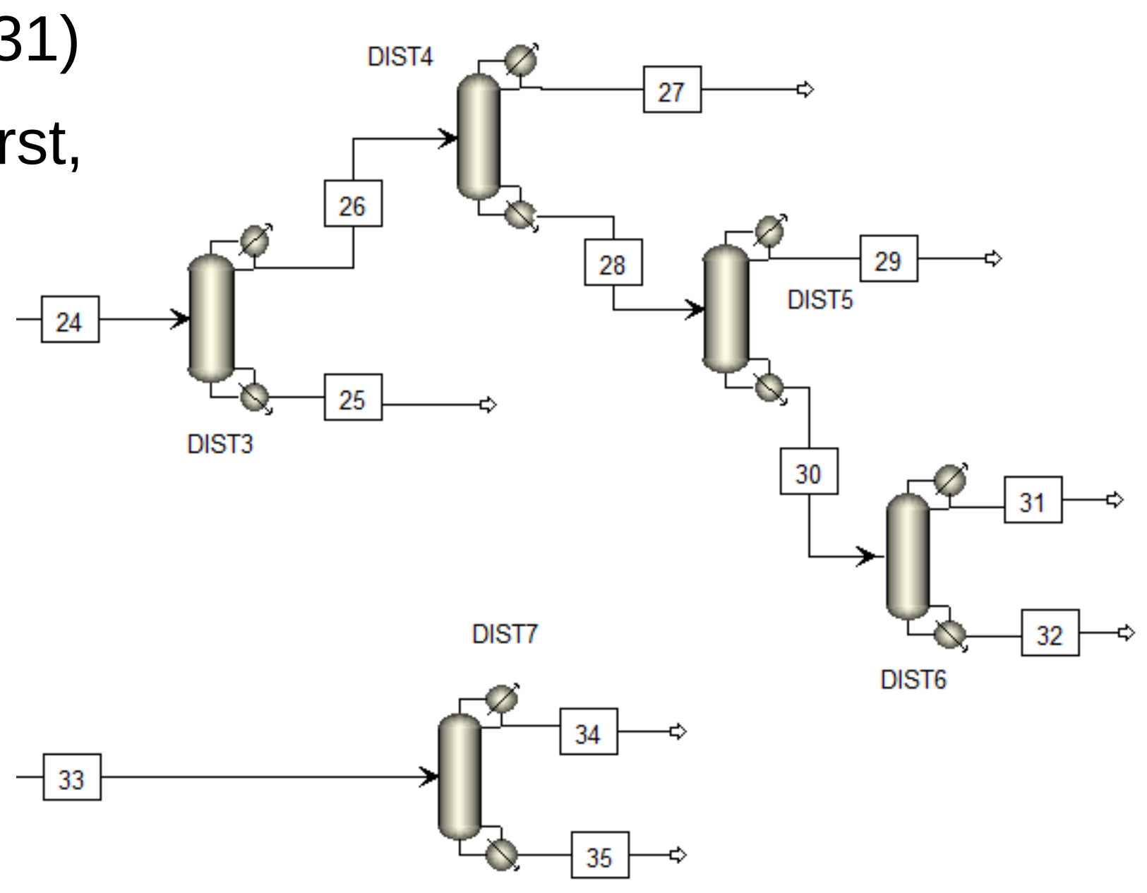


Image: *Koch Modular* [3]

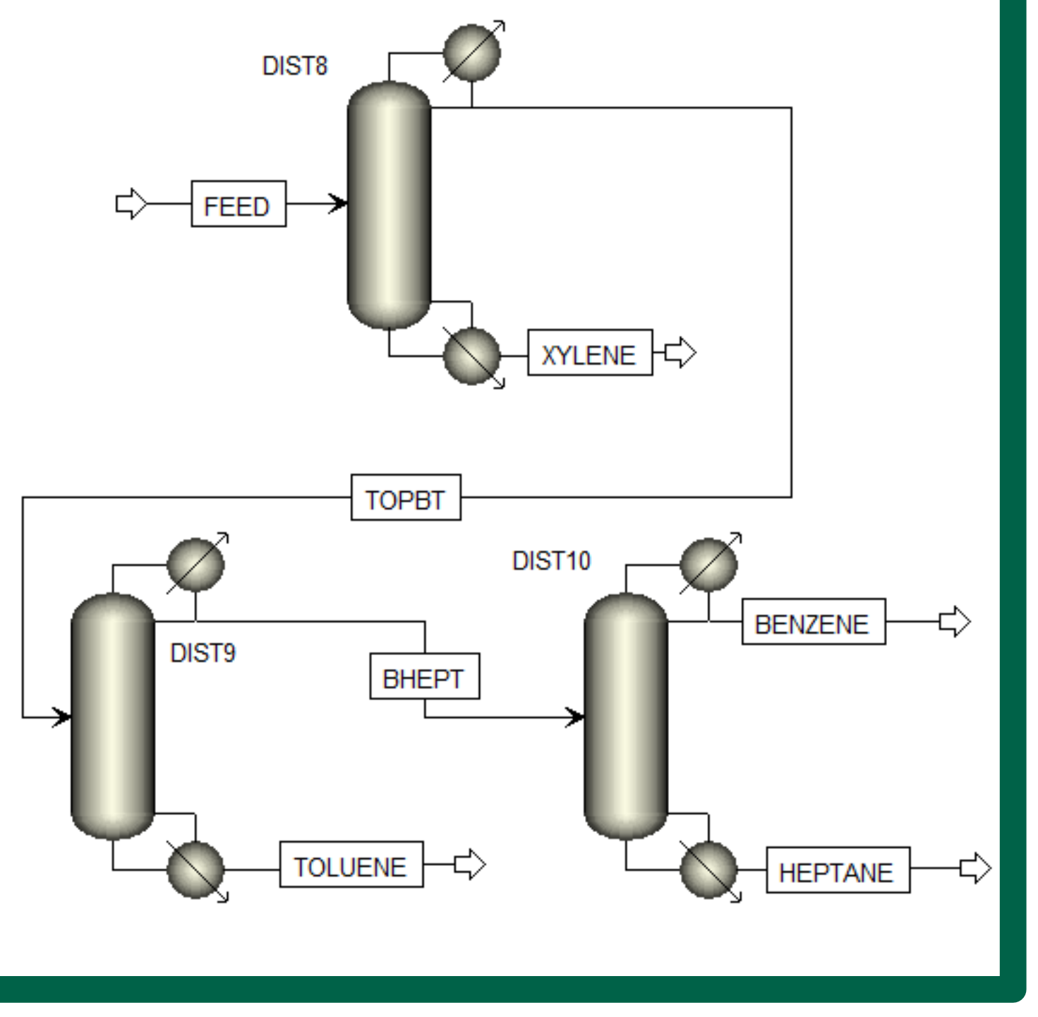
Initial Separation

- Purpose: Pure benzene stream (31)
- Separations: Light key is listed first, followed by heavy key
- DIST3: Octane and Heptane
- DIST4: Hexane and Pentane
- DIST5: Benzene and Hexane
- DIST6: Heptane and Benzene
- DIST7: Nonane and Octane
- Total Benzene Recovery: 97.8%
- Benzene Purity: 99.1%

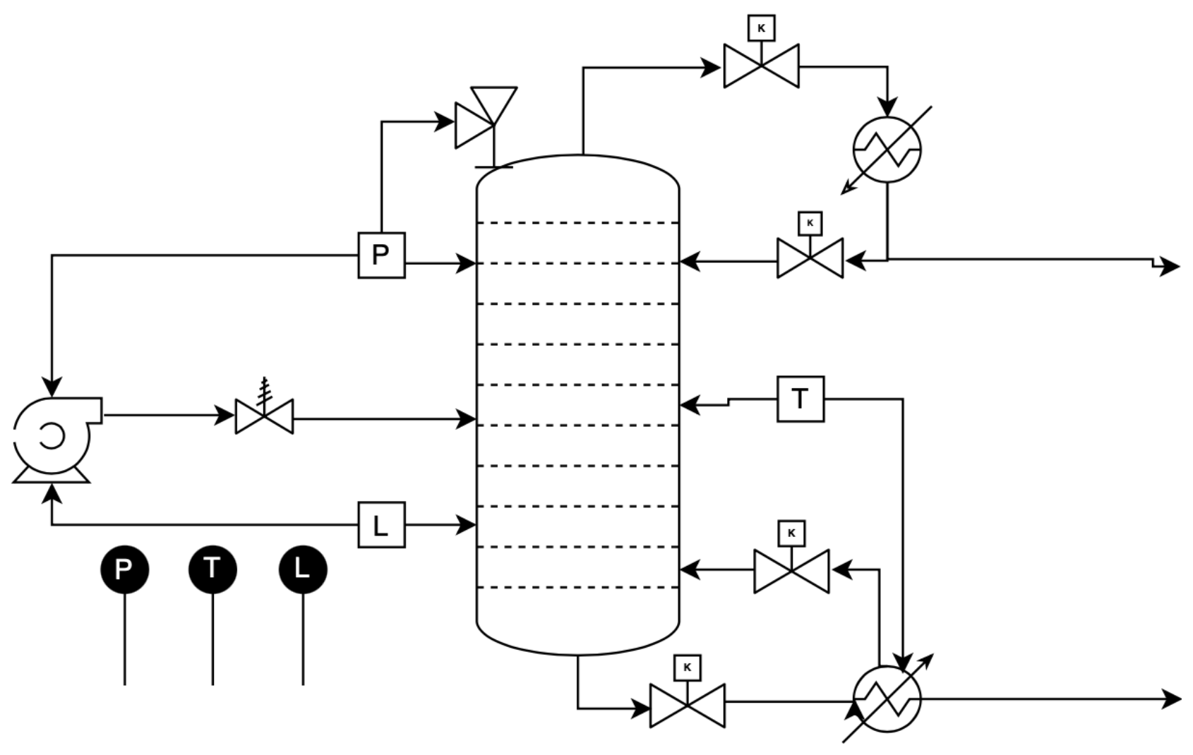


BTX Separation

- Purpose: Separate "benzene" into benzene, toluene, and xylene
- Separations: Light key is listed first, followed by heavy key
- DIST8: Remove Xylene
  - Recovery/Purity: 99.1% / 99.5%
- DIST9: Remove Toluene
  - Recovery/Purity: 99.0% / 99.4%
- DIST10: Remove Benzene
  - Recovery/Purity: 98.3% / 99.1%



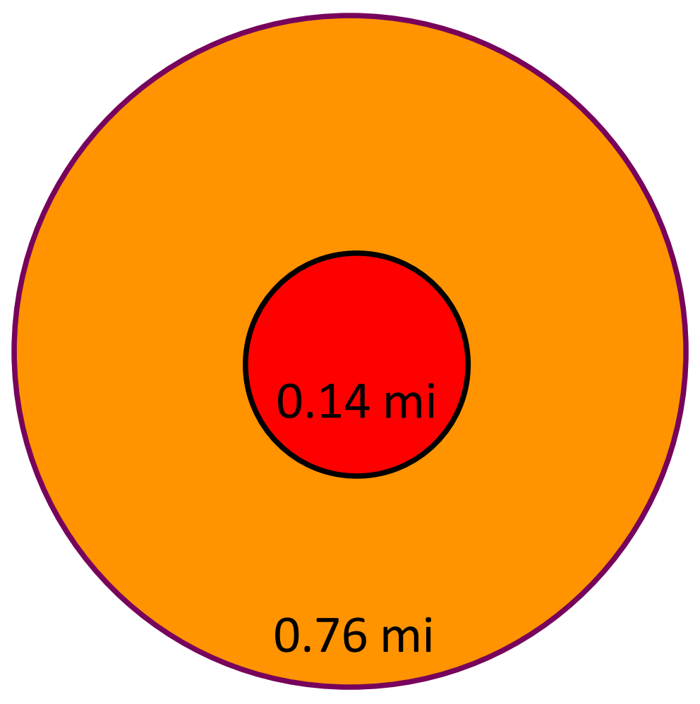
Safety Considerations



- P&ID of largest distillation tower
  - 26 m tall, 128 m³ volume
- Controls for Temperature, Pressure, and Level
- Sensors for hydrocarbon leaks

- High Temperature Hydrogen Attack
- Diffuses through carbon steels
- Forms methane and leads to failure
- Mitigated by use of 1% Chromium, 0.5% Molybdenum Stainless Steel

Image: *Process Engineering Manufacture and Control* [4]



- The largest distillation tower contains material equivalent to 5,843 kg of TNT
- In the event of an explosion:
  - Major Structural Damage 0.14 mi (Red)
  - Humans at Risk 0.76 mi (Orange)

Economics

Process Costs	
Purchase Cost ($)	5,120,000
Utilities Cost ($/yr)	6,020,000
Raw Materials ($/yr)	5,180,000
Labor Costs ($/yr)	177,000
Fixed Capital ($)	24,260,000

Revenues	
Revenue ($/yr)	253,140,000

Return on Investment (15% Tax)	
Fixed Capital ($)	24,260,000
Earnings ($/yr)	251,510,000
ROROI	831%

Return on Investment (35% Tax)	
Fixed Capital ($)	24,260,000
Earnings ($/yr)	251,510,000
ROROI	617%

Acknowledgements and References

We would like to thank the Chemical and Biomedical Engineering Department and our professor Dr. Chelsea Monty-Bromer for her assistance throughout this project.

[1] AICHE. "2020-2021 Student Design Competition Problem Statement and Rules."

[2] Talaghat, M. R. (2017). A Novel Study of Upgrading Catalytic Reforming Unit by Improving Catalyst Regeneration Process to Enhance Aromatic Compounds, Hydrogen Production, and Hydrogen Purity. *Journal of Chemical and Petroleum Engineering, 51*(2), 81-94.

[3] Koch Modular. "Extraction Column Types: Agitated and Static Columns for Liquid-Liquid Extraction."

[4] Process Engineering Manufacturing. "Detecting and Managing High Temperature Hydrogen Attack."