

# MOLLYCULE

CEO : HARSHT JAISWAL

# OVERVIEW



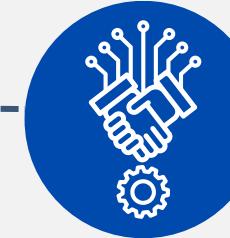
## R&D

Innovating methods for chemical synthesis including chemical reactions and steps for purification.



Fluroxypyr

Pymetrozine



## Technical Analysis

Developing a scaled up process with material balance, unit operations and operating conditions

## Market Analysis

Searching high value chemicals and calculating profit and feasibility analysis.



## Environment and Safety

Identifying safety concerns and monitor waste generation.

# MEET THE TEAM

## Research and Development

- Dhruv Bajaj
- Somya Yadav
- Prabhakar Raj
- Rutul Bhanushali

## Market Analysis

- Harshit Anand
- Vishesh Vishwakarma
- Divya Mhetre

## Technical Analysis

- Karan Keer
- Adarsh Raj
- Ankit Yadav
- Shreyas Gupta

## Environment and Health Safety

- Harshit Tomar
- Vishal Raj
- Chandan Achary
- Hershil

# R & D OVERVIEW

Identified and reviewed **11 different chemicals** for suitable synthesis in India. Finally, **3** different chemicals were selected based on feasibility analysis of the data provided by the market analysis team.

Studied multiple research papers and developed primary and alternative synthesis routes for all **3** chemicals pymetrozine, fluroxypyrr and polyaniline.

## Finally selected Chemicals

### PYMETROZINE

- Requires **cheap** and **easily obtained** raw materials
- **Short** process with **safe** and simple production
- **Minimizes wastewater** generation compared to traditional processes

### FLUROXYPYR

- Main process yields **high purity and yield**
- **Avoids hazardous** raw materials (e.g., **pentachloropyridine**) used in alternative routes

### PANI

- High yield (**>80%**) compared to traditional routes
- Consists of two main steps, making it easy to scale up

# MARKET OVERVIEW

## Profit Margins

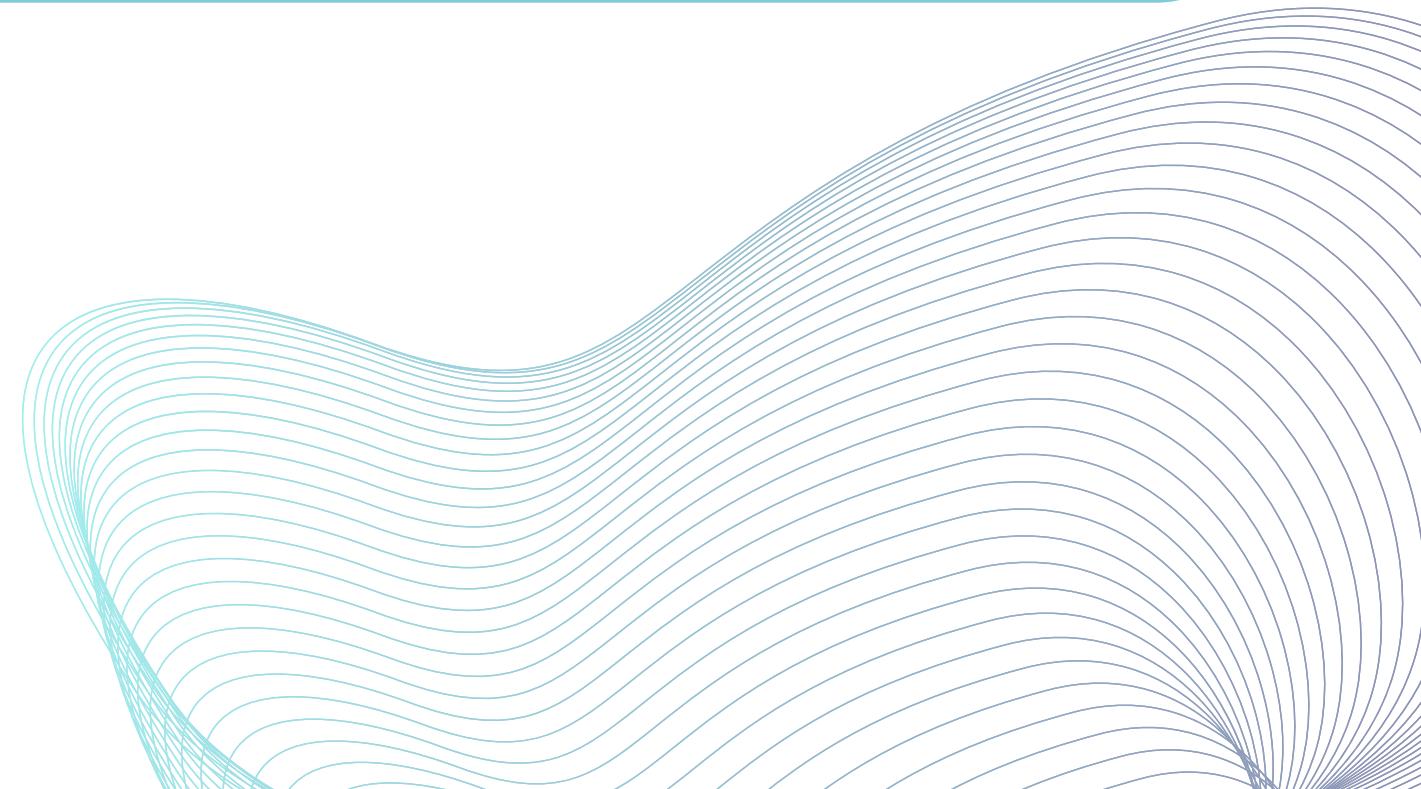
- Pymetrozine: 65.98%
- Fluroxypyr: 5.72%

## General Insights

- Both compounds benefit from local production, reducing dependency on imports.
- Strategic advantages include cost efficiency and effectiveness against resistant pests or weeds.

## Imports

- Pymetrozine: \$32.29 million imported annually, primarily from South Korea (99.97%).
- Fluroxypyr: Historically minimal imports; domestic production initiated in 2022 by Parijat Industries.



# TECHNICAL OVERVIEW

- **Scaled up** a lab synthesis to industrial scale for 1000 kg/day production of target chemicals (Fluroxypyrr and Pymetrozine).
- Conducted **mass balance** calculations along with solvent recovery and recycling loops to minimize waste and maximize material utilization.
- Developed a detailed **Process Flow Diagram** (PFD), capturing all key unit operations and utilities.
- Simulated the entire production timeline using **Gantt charts** to evaluate process efficiency and identify potential bottlenecks.

## Pymetrozine

### Reactor Specs

- Jacketed, agitated, and glass-lined carbon steel (GLCS)
- Operated at 70% working volume



## Fluroxypyrr

### Reactor Specs

- Jacketed, agitated, and glass-lined carbon steel (GLCS)
- Operated at 70% working volume



### Capital Cost

- Estimated total reactor setup cost: \$319,700 ( $\approx$  ₹2.73 Crores)
- The average cost of the reactors were around \$100k.

### Capital Cost

- Estimated total reactor setup cost: \$126,870  $\approx$  ₹1.09 Crores
- The cost of separate equipments have been described in detail later.

# **PROCESS ANALYSIS OF PYMETROZINE**

# MAIN SYNTHESIS ROUTE

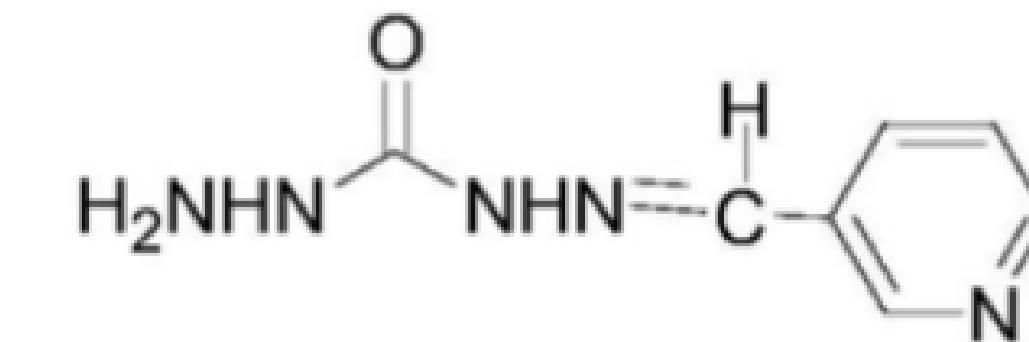
This is a simple three-step lab scale process for pymetrozine involving hydrazidation, condensation with 3-formylpyridine, and cyclization with monochloroacetone.

## STEP 1: HYDRAZIDATION REACTION:



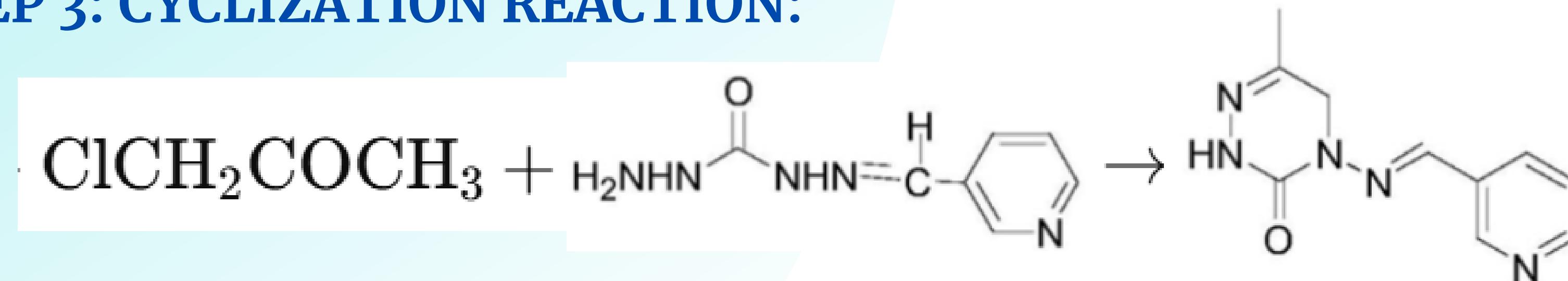
1. Carbonate ester is converted into hydrazide using hydrazine hydrate in a solvent mixture.
2. The optimal mol ratio of hydrazine hydrate to carbonate ester is 2.2-3. The favorable temperature is 75-80°C. The time of reaction is 2-4 hrs.
3. This reaction yields carbodihydrazide with a high yield of 98.8%.

## STEP 2: CONDENSATION REACTION:



1. Carbodihydrazide formed and 3-formylpyridine reacts in a suitable solvent such as ethanol or THF with a molar ratio of **0.95-1.1**.
2. The optimal temperature range is from **65 to 75°C**.
3. Pyridin-3-ylmethylenecarbodihydrazide is formed achieving a yield of **99.4%** .

### STEP 3: CYCLIZATION REACTION:



1. Monochloroacetone and compound formed earlier reacts in the presence of acid-binding agent with a optimal molar ratio of **0.95-1.1**.
  2. The temperature should be between **40-70°C**.
  3. Finally, pymetrozine with a yield of **96.6%** was formed.
- The overall process is complemented by purification steps, including crystallization, washing, and drying, which enhance the final product's purity to over 99.5%*

# ALTERNATIVE SYNTHESIS ROUTE

This is also a simple three-step lab scale process

- The first step involves the **acidolysis** of **kharophen triazone** in the presence of a mineral acid (e.g., HCl, H<sub>2</sub>SO<sub>4</sub>, H<sub>3</sub>PO<sub>4</sub>) to form aminotriazine acid salt. The yield is **98%** for this step. Reaction temperature of 30–60°C is needed. The reaction takes 3–10hrs to complete.
- The **aminotriazine acid salt** undergoes a **condensation** reaction with **nicotinaldehyde**, forming **pymetrozine hydrochlorate**. The yield is **96–98%**. The favourable temperature is 30–90°C (but somewhat higher than 30 is desirable). This step takes 2.5–5 hrs for completion.
- **Pymetrozine hydrochlorate** is neutralized using an alkali to yield **pymetrozine** in its final purified form. The alkali selected is **17% Ammoniacal liquor**. After crystallization and drying the purity reaches **97.2–98%**.

*After the synthesis process, the yield of pymetrozine is approximately 95% based on optimized reaction conditions. On improving efficiency and reducing waste can give a higher yield increased by 2.0–5.0%. The final purity can go as high as 97% by employing different purification steps such as filtration, drying, recrystallization.*

# **PROCESS ANALYSIS OF FLUROXYPYR**

# SYNTHESIS

## 1 Phase Transfer Catalysis

- Starting with 4-Amino-3,5-dichloro-2,6-difluoropyridine as the substrate. The process involves esterification with ethyl glycolate under reflux conditions
- Hydrolysis of ester intermediate yields Fluroxypyrr as a white crystalline solid with a purity of 85–95%.
- The separation steps, including liquid-liquid extraction, drying, crystallization, and vacuum drying, ensure a final purity exceeding 95%.
- This method achieves an overall yield of 85–95%, making it efficient for lab-scale synthesis

## 2 Phase Transfer Catalysis

- Starting with pentachloropyridine and proceeding through four stages: nucleophilic substitution to form 3,5-dichloro-2,4,6-trifluoropyridine, ammonation and hydrolysis to produce potassium 4-amino-3,5-dichloro-6-fluoro-2-pyridinate, alkylation with methyl chloroacetate, and transesterification with 2-octanol to yield Fluroxypyrr.
- This method incorporates advanced separation techniques, such as phase separation using N-methyl-2-pyrrolidone and organic layer extraction, followed by drying and solvent removal.
- The final product achieves a purity of >94%, though the overall yield is lower at 47.8–54.2%.

# **PROCESS ANALYSIS OF POLYANILINE**

# SYNTHESIS

## Main Synthesis Route – Oxidative Polymerization

### 1 Preparation of the Reaction Mixture

- Fresh aniline is reacted with strong HCl in order to prepare the protonated solution.
- Vigorous stirring ensures complete protonation of aniline.
- The purity of the protonated solution depends on the starting aniline. With freshly distilled aniline and good temperature control, the purity can exceed 99%.

### 2 Oxidative Polymerization

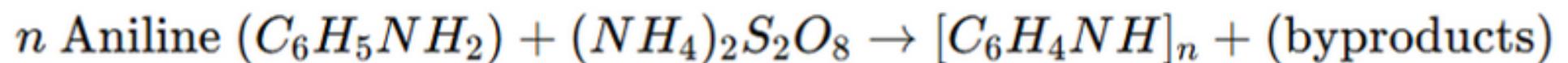
- The previously protonated solution is oxidized using ammonium persulfate which yields **Polyaniline** as some byproducts which include ammonium and sulfate salts.
- Moderate to Vigorous is applied to ensure even distribution of oxidant.
- The crude purity is about 70-80% but after further purification and isolation steps like filtration, washing and drying, the final purity goes upto 90-95%. Similarly, the final yield is about 60-70%.

## 3

## Dedoping / Redoping

- Polyaniline is subjected to a dedoping process using a mild base, which removes the protonic acid dopants and converts the polymer into its non-conductive emeraldine base form. This is subsequently followed by re-doping with a specific acid, allowing for precise tailoring of the material's electrical conductivity, solubility, and other properties.

### Overall Reactions:



#### 1. Dedoping:



( $\text{PANI}^+ X^-$  = protonated emeraldine salt;  $X^-$  = counter-anion)

#### 2. Re-Doping:



( $H^+ Y^-$  = chosen doping acid; final doping modifies conductivity or solubility.)

# SYNTHESIS

## Alternate Synthesis Route – Interfacial Polymerization

**Overview:** Interfacial polymerization synthesizes polyaniline by polymerizing aniline at the boundary between an organic solvent phase and an aqueous acidic phase. This method uses the phase boundary to control the reaction, often requiring milder conditions or initiators. The process typically produces nanostructured PANI (e.g., nanofibers or films) with good conductivity and morphology control. Below are the detailed steps :

### 1 Preparation of the Two-Phase system

- Freshly distilled aniline is dissolved in an organic solvent (e.g. chloroform, toluene) with gentle stirring/ Separately, the aqueous phase is prepared by dissolving HCl in distilled water.
- This step only involves physical separation of phases and no chemical reactions. The two solutions are kept separately until the next step.

## 2

## Interfacial Polymerization

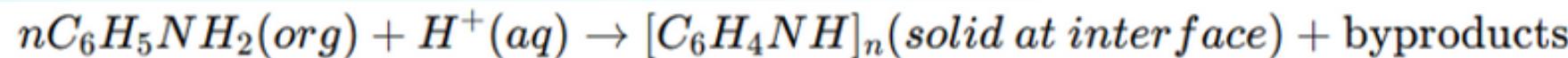
- The organic phase (e.g., aniline in chloroform) is carefully layered over or under the aqueous phase (depending on solvent density; chloroform sinks, toluene floats). Polymerization begins spontaneously at the interface as aniline diffuses into the acidic phase, forming a green PANI film (emeraldine salt). Gentle agitation is maintained until the desired thickness of the product is achieved.
- Crude yield ranges from 70–85% based on aniline, as some monomer remains unreacted in the organic phase. Whereas, the crude purity is about 70–80%. After the crude PANI is subjected to purification and separation steps the final purity goes up to 90–95% and the final yield is about 60–75%.

## 3

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### Overall Reactions:



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# **MARKET ANALYSIS OF PYMETROZINE**

# MARKET ANALYSIS

## India's Imports:

- \$32.29 million worth of Pymetrozine imported annually.
- South Korea dominates with 99.97% of imports; Switzerland accounts for 0.01%.

## Economic Feasibility:

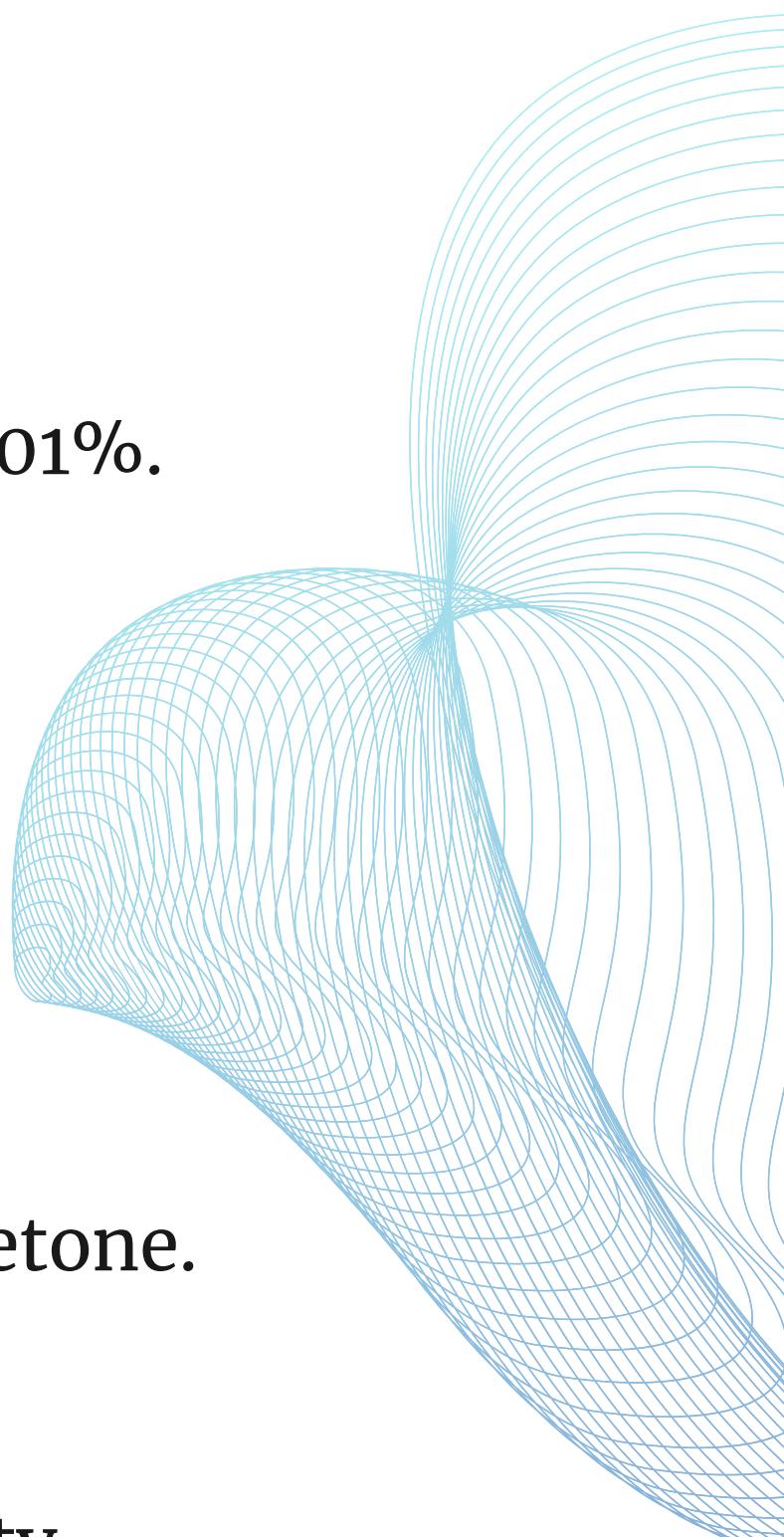
- Raw Material Costs: ₹184,747 per kmol of Pymetrozine.
- Revenue: ₹543,075 per kmol of Pymetrozine.
- Profit Margin: 65.98%.

## Key Raw Materials:

- Dialkyl carbonate, hydrazine hydrate, 3-formylpyridine, and monochloroacetone.

## Market Opportunity:

- Local production can reduce dependency on imports and improve profitability.



## Use Cases:

- **Controls sap-feeding insects:** Effectively manages aphids, whiteflies, leafhoppers, and planthoppers.
- **Key crops:** Used in potatoes, tomatoes, cotton, rice, and cereal crops.
- **IPM:** Compatible with Integrated Pest Management, safe for beneficial insects.
- **Low environmental impact:** Reduced toxicity to non-target organisms.
- **Resistance management:** Helps prevent resistance due to its unique mode of action

## Advantages Over Alternatives:

- **Selective Pest Control:** Targets sap-feeding insects, minimizing harm to beneficial species in IPM.
- **Resistance Management:** Unique mode of action helps manage resistance to common insecticides.
- **Environmentally Sound:** Reduces toxicity to non-target organisms, supporting sustainable practices.

# **MARKET ANALYSIS OF FLUROXYPYR**

# MARKET ANALYSIS

## India's Imports:

- India's import of Fluroxypyrr was historically minimal, with an instance of 1 litre imported from the U.S. for \$299 in October 2016.
- However, a significant shift occurred in April 2022 when Parijat Industries initiated domestic production of Fluroxypyrr with 97% purity, reducing the country's reliance on imports.

## Key Raw Materials:

- 4-Amino-3,5-dichloro-2,6-difluoropyridine, Ethyl glycolate, Potassium carbonate (catalyst), and Toluene (solvent).

## Market Opportunity:

- Reduce dependency on imports through local production, offering a strategic advantage.

## Economic Feasibility:

- Raw Material Costs: ₹6,01,046 per kmol of Fluroxypyrr.
- Revenue: ₹6,37,575 per kmol of Fluroxypyrr.
- Profit Margin: 5.72%.

## Use Cases:

- **Turf Management:** Weed control in sports fields, golf courses, and ornamental lawns.
- **Agriculture:** Used in cereals (wheat, rice, corn), sugarcane, onions, and pastures.
- **Plantation Crops:** Applied in orchards (e.g., apple) and plantations like rubber and oil palm.

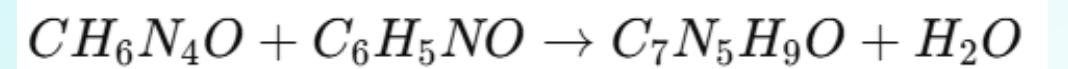
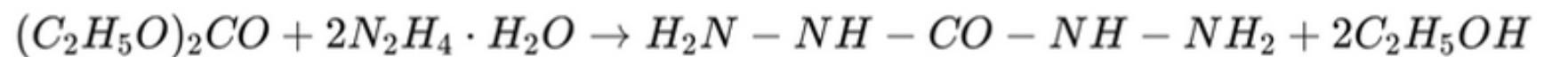
## Advantages Over Alternatives:

- **Selective Action:** Preserves grasses in cereal crops and turf management.
- **Glyphosate-Resistant Weeds:** Effective against glyphosate-resistant weeds like Kochia.
- **Long-Term Activity:** Reduces regrowth of invasive species.

# **TECHNICAL ANALYSIS OF PYMETROZINE**

# TECHNICAL ANALYSIS

Objective: Design a complete process for synthesizing Pymetrozine ( $C_{10}H_{11}N_5O$ ) using industrially viable steps.



## 1 Step 1: Synthetic Route Optimization

Scaled up lab-based synthesis to industrial level by selecting appropriate reactor types, defining temperature/pressure conditions, and integrating three-step synthesis into a continuous process.

## 2 Process 02 – Flow Diagram & Equipment Selection

Designed the process flow diagram including jacketed stirred reactors (R-1 to R-3), crystallizer (C-1), heat exchangers (H-1, H-2), washer (W), and dryer (D), ensuring efficient thermal and phase control across units.

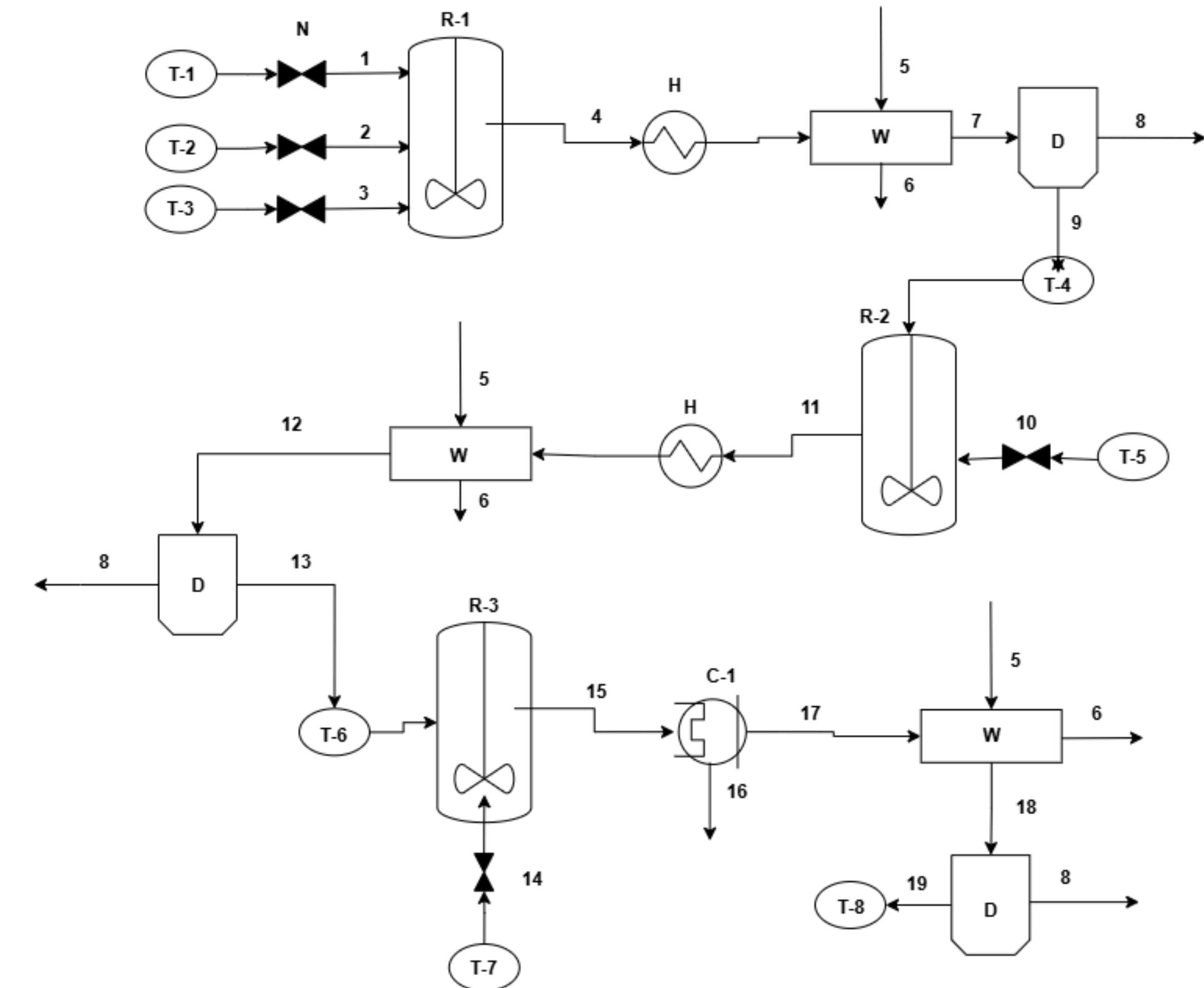
## 3 Process 03 – Process Design Choices

Operated at atmospheric pressure with 25–70 °C range, sized reactors based on 70% working volume, selected recyclable solvents (ethanol/THF), and accounted for utility integration and solvent recovery for sustainability.

# TECHNICAL ANALYSIS

## Scale-Up and Mass Balance

- Process scaled to 1000 kg/day pymetrozine output based on stoichiometric ratios and reaction yields
- Input and output flow rates calculated for all streams using simplified assumptions (100% conversions where needed)
- Accounted for solvent loss, recycle, and waste to ensure material accountability



Process Flow Diagram

# REACTOR SIZING – STAGE-WISE VOLUME ESTIMATION

Reactor	Total Mass in reactor (kg/day)	Estimated Volume (L)	Design Volume (L) (70% utilization)
Reactor 1	9,712	10,283	14,690
Reactor 2	11,696	13,207	18,867
Reactor 3	12,405	13,990	19,985

- Volumes based on individual component densities.
- Final design volumes account for 70% working capacity.
- Reactors designed for jacketed, agitated, glass-lined carbon steel (GLCS).

# CAPITAL COST ESTIMATION – REACTOR SETUP

Reactor	Design Volume (L)	Design Capacity (gal)	Units	Cost/Unit (\$)
Reactor 1	14,690	3,880.7	1	96,300
Reactor 2	18,867	4,984.1	1	110,000
Reactor 3	19,985	5,279.5	1	113,400

Total Capital Cost:

\$319,700 ≈ ₹2.73 Crores

(Based on Matche Equipment Cost Calculator; Pressure: 1–25 psi)

# REACTOR SIZING – STAGE-WISE VOLUME ESTIMATION

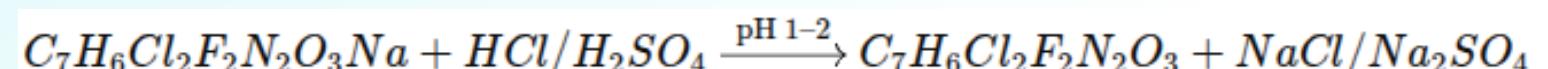
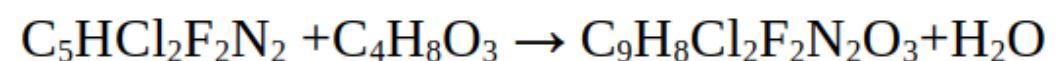
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# **TECHNICAL ANALYSIS OF FLUROXYPYR**

# TECHNICAL ANALYSIS

Objective: Design a complete process for synthesizing Fluroxypyrr ( $C_6H_4Cl_2FN_2O_3$ ) using industrially viable steps.



1

## Step 1: Reaction Upscaling

Based on the work done by the R&D team, we took the proposed reactions and worked on scaling them up to an industrial level. We ensured catalyst recovery and defined suitable pressure and temperature conditions for each step.

2

## Step 2: Process Flow Design & Batch Planning

A Gantt chart was created to schedule batch operations and determine the number of simultaneous batches needed to achieve the target of 1000 kg/day. Based on this analysis, suitable reactors and supporting equipment were selected to ensure efficient processing and continuous flow where required.

3

## Step 3 – Key Design Considerations

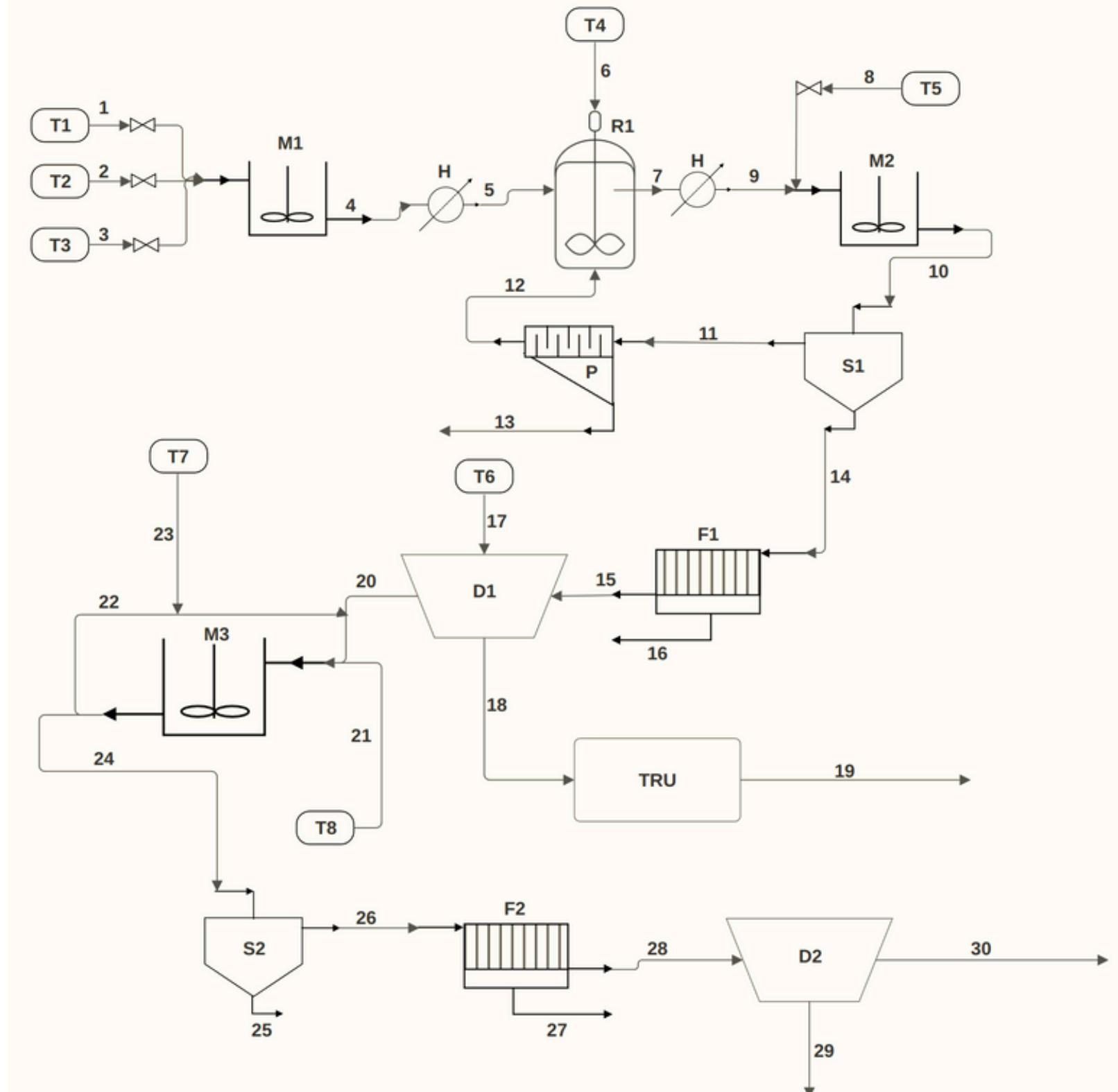
The process was operated at atmospheric pressure within a 25–70 °C range, with reactors sized at 70% working volume. The expensive catalyst TiBAI was recovered, and all potassium salts formed were sent for proper treatment. Reusability of reactors was addressed using the Gantt chart to schedule simultaneous batches.

# TECHNICAL ANALYSIS

## Scale-Up and Mass Balance

- Process scaled to 1000 kg/day fluroxypyrr product feed based on stoichiometric ratios and reaction yields
- Input-output flow rates calculated while assuming reasonable values of product yield provided by the R&D department
- Solvent loss and by-products were also accounted for in the overall mass balance to ensure material accountability.

## Process Flow Diagram:



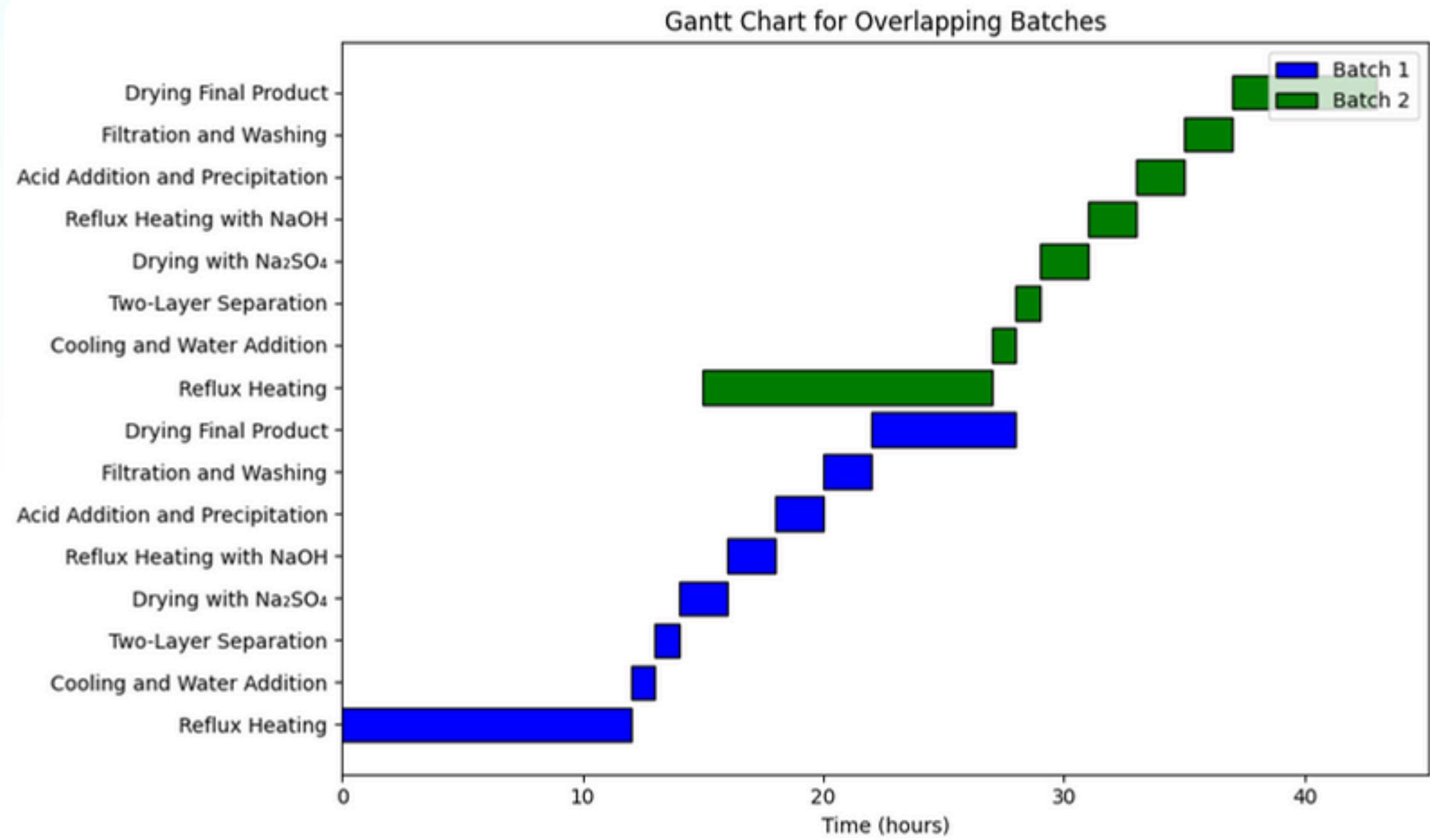
# TECHNICAL ANALYSIS

## Bottleneck Analysis

- Initial process design reused the same Nutsche filter and vacuum dryer for both Fluroxypyrr Ethyl Ester and the final Fluroxypyrr product. Gantt chart simulation revealed a critical bottleneck:
- Drying took 6 hours, causing delays as subsequent batches were ready for filtration while the equipment was still occupied.
- Solution Implemented:
  - Added a second Nutsche filter and vacuum dryer.
  - Enabled parallel batch processing during filtration and drying.
  - Eliminated idle time and significantly improved throughput without extending batch cycles.

This optimization ensured a smoother workflow and enhanced process efficiency.

## Gantt Chart



# REACTOR SIZING – STAGE-WISE VOLUME ESTIMATION

Reactor	Estimated Volume (L)	Design Volume (L) (70% utilization)
Batch Reactor	10,502	15,003.3
Jacketed Mixing Vessel	5896.7	8,500
Jacketed Mixing Cooler	15243.7	21,776.7
2-Layer Seperator	15243.7	21,776.7
Nutsche Filter & Vacuum Dryer 1	10,500	15000
Nutsche Filter & Vacuum Dryer 2	5772.12	8245.77

- Volumes based on individual component densities.
- Final design volumes account for 70% working capacity.
- Reactors designed for jacketed, agitated, glass-lined carbon steel (GLCS).

# CAPITAL COST ESTIMATION – REACTOR SETUP:

Reactor	Design Volume (L)	Units	Cost/Unit (\$)
Batch Reactor	15,003.3	1	33,000
Jacketed Mixing Vessel	8,500	1	9,800
Jacketed Mixing Cooler	21,776.7	1	20,000
2-Layer Seperator	21,776.7	1	20,000
Nutsche Filter & Vacuum Dryer	15000	2	22,000

Total Capital Cost:

\$126,870 ≈ ₹1.09 Crores

(Based on Matche Equipment Cost Calculator; Pressure: 1–25 psi)

# **Environment, Health and Safety Report**

# EHS REPORT

At Mollycule, we recognize the critical importance of environmental stewardship and workplace safety in the chemical industry. As part of our commitment to these principles, we have conducted a comprehensive Environmental, Health, and Safety (EHS) analysis of our processes, identify safety concerns, estimating the amount of waste generation, estimating the EQ Factor & proposing a plan to monitor and treat the environmentally benign compounds for disposal.

# Fluroxypyrr ( $C_7H_5Cl_2FN_2O_3$ )

## Production Rate: 1382 kg/h

Reactants Required: 2244.2 kg/h

Total Waste Production: 862.2 kg/h

Waste Stream	Quantity (kg)	Source
Unreacted 4-Amino-3,5-dichloro-2,6-difluoropyridine	75.9	Remaining after 92% reaction completion
Unreacted Ethyl Glycolate	43.7	Remains after reaction
Water (produced during reaction)	79.1	Reaction byproduct
Excess $K_2CO_3$	184.75	Catalyst/base used in excess
TBAI (catalyst waste)	88.2 (13.2 lost)	Phase transfer catalyst
Hydrated $Na_2SO_4 \cdot 10H_2O$	118.65	Drying agent waste
Ethanol (from hydrolysis)	198.3	Byproduct of ester hydrolysis
NaCl (from acidification)	73.6	Byproduct of final acidification

Atom Economy: 61.58%

E-Factor: 0.624

EQ-Factor: 2.62\*

## RCRA Regulated Wastes

Name	RCRA Category	What the Category Means
Toluene (Unused)	U220	Toxic waste that is unused and must not be disposed of in drains or regular trash.
Toluene (Used)	F005	Listed hazardous waste, specifically flammable solvents that must be treated as hazardous.
Ethanol	D001	Flammable hazardous waste; large amounts require hazardous waste disposal.
Sodium Hydroxide	D002	Corrosive hazardous waste that must be kept separate from organic solvents.
Potassium Carbonate	Not specifically regulated	Should be neutralized before disposal due to its basic nature.
Aqueous Solutions	Depends on contents	If containing RCRA-regulated toxic chemicals, must be disposed of as hazardous waste.

## Hazardous Wastes and Intermediates

Chemical	TWA (8-hr)	STEL (15-min)	Primary Risk
Hydrazine	0.01 ppm	0.03 ppm	Carcinogenic
Ethanol	1000 ppm	1500 ppm	Flammable
Hydrochloric Acid	2 ppm	5 ppm	Corrosive
3-Formylpyridine	0.05 mg/m³	0.15 mg/m³	Neurotoxic

\*the source for Q values in the report were a bit inaccurate

# Methods for Dealing with Wastes

## Treatment Procedure for Zero Liquid Discharge Plant

- Two-Layer Separation System
  - Estrification to separate into Organic and Aqueous
- Aqueous Phase Treatment
  - Catalyst Recovery through Precipitation [ $K_2CO_3$  (80% recovery) and TBAI (85% recovery)]
  - Neutralization of basic compounds
- Organic Phase Treatment
  - Water removal using  $Na_2SO_4$
  - Filtration to remove hydrated  $Na_2SO_4 \cdot 10H_2O$
  - Vacuum distillation to recover toluene
  - Collection of Fluroxypyrr Ethyl Ester
- Hydrolysis Process Treatment
  - Reaction of Fluroxypyrr Ethyl Ester with  $NaOH$  (98% yield)
  - Ethanol recovery through distillation (198.3 kg)
  - Acidification with  $HCl$  to pH 1-2 to precipitate Fluroxypyrr
  - Collection of  $NaCl$  byproduct (73.6 kg)
- Final Product Isolation
  - Filtration using Nutsche filter
  - Vacuum drying at 50°C for 6 hours
  - Final product collection (high purity >95%)

## Other Recommendations

- Multi-Effect Evaporator: Removes 90% water content at ~80°C.
- Corrosive wastes should be separated from organic solvents
- Nonhalogenated organic solvents should be separated from halogenated organic solvents
- Containers must be properly labeled and sealed to prevent spillage
- Ensure adequate ventilation in areas where chemicals are handled to prevent vapor accumulation.
- Salt Cake Disposal: Solidified salts mixed with cement for safe landfill.

# Pymetrozine ( $C_{10}H_{11}N_5O$ )

## Production Rate: 1000 kg/h

Reactants Required: 2607 kg/h

Total Waste Production: 1607 kg/h

Stage	Waste Type	Quantity/Batch	Composition
1	Liquid	724 g	Ethanol (40%), Water (50%), Hydrazine (6%)
2	Liquid	339 g	Ethanol (65%), Water (35%)
3	Liquid	519 g	Ethanol (45%), Water (50%), KCl (5%)
All	Solid	25 g	KCl, unreacted organics

**Atom Economy: 79.4%**

**E-Factor: 0.33**

**EQ-Factor: 3.06\***

Waste Type	Quantity (per batch)	RCRA Classification	Treatment/Disposal
Hydrazine	46 g	Acute Hazardous Waste (F027/P-list)	Neutralization or incineration (<0.01 mg/L)
Ethanol (40%-65%)	292 g - 439 g	Ignitable Waste (D001/F003)	Distillation or biodegradation (<5 mg/L)
Water	365 g - 50% of waste	Contaminated Water	Effluent treatment (BOD <30 mg/L, COD <250 mg/L)
Potassium Chloride (KCl)	25 g	Saline Pollutant	Stabilization or landfill disposal (<60 mg/L leachate)
Wash Water	20 g - 80 g	Contaminated Water	Effluent treatment (BOD <30 mg/L, COD <250 mg/L)
Unreacted Organics	Trace amounts	Toxic Waste (D004-D043)	Incineration or stabilization for landfill disposal

\*the source for Q values in the report were a bit inaccurate

# Methods for Dealing with Wastes

## Treatment Procedure for Zero Liquid Discharge Plant

- Pre-Treatment
  - Remove coarse solids, oils, and grease through filtration and chemical neutralization.
  - Adjust pH levels for compatibility with downstream processes.
- Membrane Technologies
  - Use ultrafiltration and reverse osmosis to recover up to 80% of water, concentrating contaminants into brine streams.
- Evaporation and Crystallization
  - Employ vacuum evaporators and crystallizers to further concentrate brine and extract salts like KCl for reuse or disposal
- Water Recovery
  - Recycle purified water back into industrial processes, reducing freshwater dependency by up to 95%

## Other Recommendations

- Convert filtration residual solids into stable forms for landfill disposal or reuse as raw materials
- Multi-Effect Evaporator: Removes 90% water content at ~80°C.
- Recover Ethanol from Liquid waste via distillation for reuse.
- Neutralize hydrazine and other hazardous substances using advanced oxidation or incineration.
- Nonhalogenated organic solvents should be separated from halogenated organic solvents
- Containers must be properly labeled and sealed to prevent spillage
- Ensure adequate ventilation in areas where chemicals are handled to prevent vapor accumulation.
- Salt Cake Disposal: Solidified salts mixed with cement for safe landfill.

# Other Recommendations for both Processes

- Corrosive wastes should be separated from organic solvents
- Nonhalogenated organic solvents should be separated from halogenated organic solvents
- Containers must be properly labeled and sealed to prevent spillage
- Use PPE during handling and ensure proper containment of hazardous materials.
- Exposures at STEL must not exceed a duration of more than 15 minutes at a time.
- A minimum interval of one hour should separate successive exposures at STEL levels, with not more than 4 times a day
- Ensure adequate ventilation in areas where chemicals are handled to prevent vapor accumulation.
- Store chemicals in designated areas away from incompatible substances such as oxidizers or heat sources.
- Use absorbents for spills and dispose of them as hazardous waste according to local regulations.
- Critical Controls for All Chemicals
- Install LEV systems for capturing hazardous vapors at the source.

# THANK YOU

