

## Chemical molecule and synthesis route

**Applicant:** VortexChem

**Inventors:** Vivek Pawar , Aryan Kadam

**Chemical Formula:**  $C_6H_{16}N_2$

**Chemical Name:** Hexamethylenediamine (HMDA)

HMDA (Hexamethylenediamine) is a fine chemical because it is a high-purity, specialty chemical used mainly in nylon 6,6 production. It requires a complex synthesis process, is produced in lower volumes compared to bulk chemicals, and has specific high-value applications in polymers and coatings.

## PRIMARY SYNTHESIS METHODS

### Adiponitrile Hydrogenation

Adiponitrile (ADN) hydrogenation represents the dominant commercial pathway for HMDA production. This process involves catalytic hydrogenation of the nitrile groups to form primary amines.

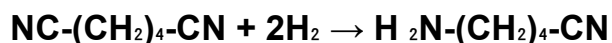
### Raw Materials and Chemicals Required

- 1.) Adiponitrile (  $NC(CH_2)_4CN$  )
- 2.) Hydrogen ( $H_2$ )
- 3.) Ammonia ( $NH_3$ )
- 4.) Catalyst: Raney nickel or Raney cobalt
- 5.) Water (as reaction medium)
- 6.) Cooling water (for heat management)

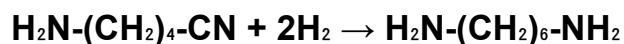
### Reaction Steps & Yields

The hydrogenation of adiponitrile to HMDA proceeds via the following mechanism:

- 1.) **Initial Hydrogenation** - Adiponitrile is partially hydrogenated to form the intermediate 6 - amino hexanenitrile (AHN).



**2.) Complete Hydrogenation** - The intermediate undergoes further hydrogenation to form HMDA.



Reported yields vary based on reaction conditions:

- Using Raney Ni catalyst: >90% HMDA yield at optimized conditions.
- Using Raney Co catalyst: 85-87% HMDA yield.

### **Reaction Conditions**

**Temperature** - 60 - 100°C (optimal between 80-100°C for Raney Ni catalyst).

**Pressure** - Laboratory scale typically uses 2-3 MPa.

**Catalyst loading** - Lower ADN/catalyst ratios improve yields.

**Reaction medium** - Liquid phase reaction in water.

**Additives** - Excess ammonia (serves to minimize undesired side reactions like formation of secondary/tertiary amines and increases hydrogen solubility).

**Reaction time** - 4-6 hours.

**Reactor type** - For lab scale, a high-pressure batch reactor with temperature control.

### **Separation steps and final purity**

- 1.) Cooling the reaction mixture
- 2.) Separation of catalyst by filtration
- 3.) Vacuum distillation in a series of columns to purify HMDA
- 4.) Separation of excess adiponitrile and byproducts (including secondary amines)

The final product purity can exceed 99% through careful distillation. As HMDA is hygroscopic it must be stored under inert gas conditions for best results .

### **Critical Factors affecting Yield and Selectivity**

- 1.) Temperatures in the range (80 - 90°C) with a further increase to 100°C boosting yield >90.5% with Raney Ni catalyst.

- 2.) Higher H<sub>2</sub> pressure increases yields as higher solubility of H<sub>2</sub> in the reaction medium would allow better interaction with the ADN and intermediates.
- 3.) Lower ADN/catalyst ratios help to enhance the conversion as it means that we have more catalyst per ADN which ensures better access to active sites speeding the hydrogenation.
- 4.) Lower ADN/HMDA ratios improves yields (optimal at ADN/HMDA volumetric ratio of 0.06)
- 5.) Excess ammonia minimizes unwanted side reactions and acts as a heat transfer agent due to the exothermic nature of the reaction.

## **ALTERNATIVE SYNTHESIS METHOD**

### **Reductive Amination of 1,6 Hexanediol**

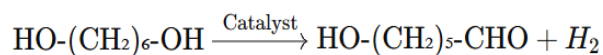
Reductive amination of 1,6 hexanediol represents one of the most promising green routes for HMDA synthesis , offering environmental advantages over conventional methods.

### **Raw Materials and Chemicals Required**

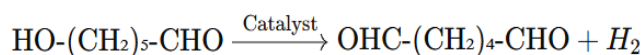
- 1.) 1,6 Hexandiol (HDO)
- 2.) Ammonia (25 % aq solution)
- 3.) Hydrogen (H<sub>2</sub>)
- 4.) Catalyst options :
  - a.) Ruthenium on carbon (Ru/C)
  - b.) Modified ruthenium catalyst (Ru/PRL - Al<sub>2</sub>O<sub>3</sub>)
  - c.) Phosphorus modified nickel catalyst (Ni-P/Al<sub>2</sub>O<sub>3</sub>)
- 5.) Base additives (optional):
  - a.) Barium Hydroxide (Ba(OH)<sub>2</sub>)
  - b.) Cesium carbonate (Cs<sub>2</sub>CO<sub>3</sub>)
- 6.) Reaction solvent - Water
- 7.) Equipment - High pressure reactor with temperature control and stirring capability

### **Reactions Steps and Yields**

**1.) Initial dehydrogenation** - In the presence of a dehydrogenation catalyst, 1,6-hexanediol (HDO) undergoes dehydrogenation to form 6-hydroxyhexanal as an intermediate.

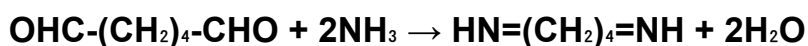


This reaction occurs at both hydroxyl (-OH) groups sequentially, leading to hexanedial.



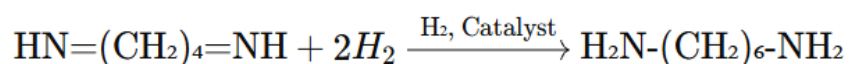
## 2.) Condensation with Ammonia (Imine Formation) -

The aldehydes react with Ammonia to form imine intermediates



## 3.) Hydrogenation of Imines (Formation of Hexamethylenediamine)

Imine intermediates are hydrogenated to form amine products



The reported yield of HMDA using  $\text{Ba}(\text{OH})_2$  as a base is approximately 34%.

This reaction pathway produces several products

- 1.) 6 - Amino - 1 hexanol (AH) - mono amination product
- 2.) 1,6 hexamethylenediamine (HMDA) - desired di amination product
- 3.) Azepane - cyclization product

## Reaction Conditions

The optimal conditions for lab scale synthesis using Ru/C catalyst are

- 1.) **Temperature** - 190°C

**2.) Hydrogen pressure** - 25 bar

**3.) Catalyst loading** - 50 mg Ru/C per 3.2 mmol HDO (substrate/catalyst ratio = 7.8 g/g)

**4.) Ammonia solution** : 17.5 ml of 25 % aq  $\text{NH}_3$

**5.) Reaction time** - 2 - 4 hours

Base addition significantly influences product selectivity

1.) Addition of  $\text{Cs}_2\text{CO}_3$  favors 6-amino-1-hexanol formation 26% yield)

2.) Addition of  $\text{Ba}(\text{OH})_2$  enhances HMDA yield (34%) and azepane formation 26% .

The  $\text{Ba}(\text{OH})_2$  addition decreases the apparent activation energy from 68 to 48 kJ/mol facilitating the initial conversion of HDO to 6-amino-1-hexanol and accelerating the reaction between ammonia and carbonyl-containing intermediates.

## **Products Yields and Catalyst Performance**

### **1.) Ru/PRL- $\text{Al}_2\text{O}_3$ catalyst -**

The total yield of HMDA and hexamethyleneimine exceeds 80%

Superior catalytic performance attributed to highly dispersed Ru species anchored by  $\text{CN}_x$  species formed from 1,10-phenanthroline PRL

Enhanced acid-base pairs and electron-deficient Ru species improve catalytic performance and stability

### **2.) Ru/C with $\text{Ba}(\text{OH})_2$ -**

HMDA yield: 34%

Azepane yield: 26%

Combined amine yield: 60%

### **3.) Ni-P/ $\text{Al}_2\text{O}_3$ catalyst -**

Phosphorus modification significantly improves selectivity toward HMDA compared to unmodified Ni/ $\text{Al}_2\text{O}_3$

Modification creates flatter Ni nanoparticles and reduces strong acid sites

Formed Ni- $\text{AlPO}_x$ - $\text{Al}_2\text{O}_3$  interface shifts product selectivity from hexamethyleneimine to HMDA

### **Separation steps and final purity**

While specific separation procedures aren't detailed in the source materials, standard procedures would include:

- 1.) Catalyst recovery by filtration at ambient temperature.
- 2.) Neutralization of excess ammonia
- 3.) Solvent removal under reduced pressure
- 4.) Product separation through distillation or crystallization
- 5.) Final purification by recrystallization if necessary

The final purity achievable depends on the separation methods employed but should reach 98% with proper purification techniques.

### **References**

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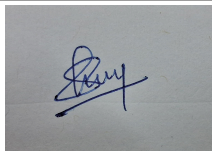
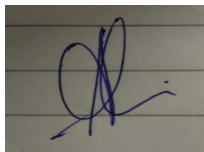
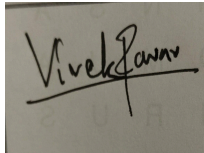
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**List the contributions of each author:**

Vivek Pawar - Carried the literature search and did research on the commercial primary synthesis method of HMDA involving adiponitrile hydrogenation and understood , studied the reactions along with the critical factors affecting yield and selectivity.

Aryan Kadam - Found research articles , literature for the alternative synthesis method using 1,6-hexanediol and studied the process to understand the reactions and their conditions , along with impact on product yields using different catalysts and use of base additives.

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