

## 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.

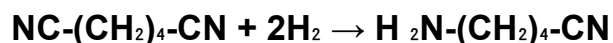
### Raw Materials and Chemicals Required

- 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)

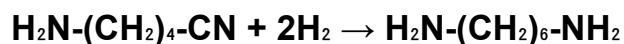
### Reaction Steps & Yields

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**

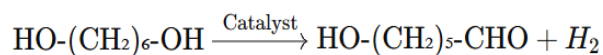
Reductive amination of 1,6 hexanediol represents one of the most promising green routes for HMDA synthesis , offering environmental advantages over conventional methods.

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

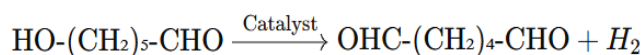
- 1.) 1,6 Hexandiol (HDO)
- 2.) Ammonia (25 % aq solution)
- 3.) Hydrogen (H<sub>2</sub>)
- 4.) Catalyst options :
  - a.) Ruthenium on carbon (Ru/C)
  - b.) Modified ruthenium catalyst (Ru/PRL - Al<sub>2</sub>O<sub>3</sub>)
  - c.) Phosphorus modified nickel catalyst (Ni-P/Al<sub>2</sub>O<sub>3</sub>)
- 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.

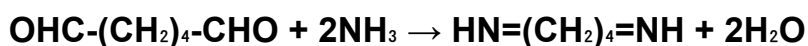


This reaction occurs at both hydroxyl (-OH) groups sequentially, leading to hexanedial.



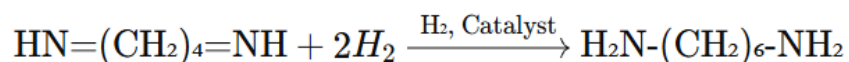
## 2.) Condensation with Ammonia (Imine Formation) -

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 Ba(OH)<sub>2</sub> 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**

<https://doaj.org/article/45f3d1dc2c684192801f413af1ae66c1>

<https://cdn.intratec.us/docs/reports/previews/hmda-e41a-b.pdf>

<https://www.globalcadataaccess.org/hexamethylenediamine-hmda-acrylonitrile-adiponitrile-hmda-hydrogenation-adiponitrile-single-route>

[https://tuprints.ulb.tu-darmstadt.de/24545/1/2022\\_ACSSustainableChemEng\\_Gupta.pdf](https://tuprints.ulb.tu-darmstadt.de/24545/1/2022_ACSSustainableChemEng_Gupta.pdf)

<https://patents.google.com/patent/EP2804848A1/en>

<https://papers.ssrn.com/sol3/Delivery.cfm/1d6ae532138c-401e-a239-f4d146012e9d-MECA.pdf?abstractid=4571960&mirid=1>

<https://www.chembk.com/en/chem/HMDA>

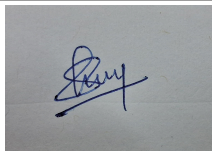
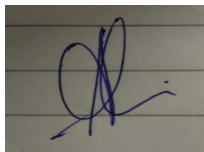
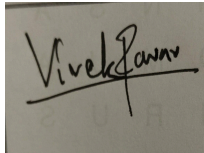
<https://www.radicigroup.com/en/products/chemicals/adipic-acid-nitric-acid-production-radichem/radichem-1326>

**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.

Sign the pdf and upload.

Name	Roll No	Signature
Kumar Shubham	230587	
Aryan Kadam	230221	
Vivek Pawar	230747	

--	--	--