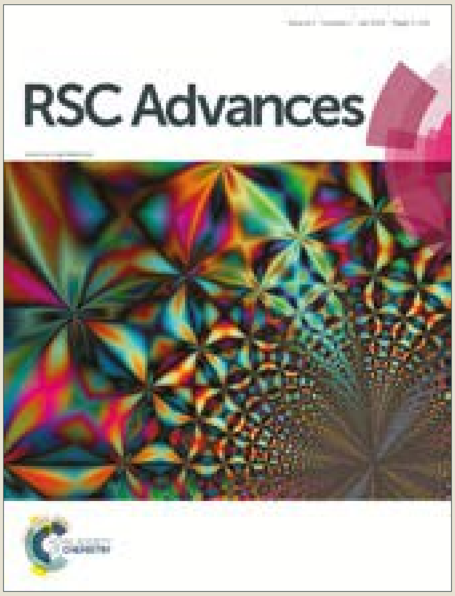
RSC Advances

Accepted Manuscript



ROYAL SOCIETY OF CHEMISTRY

rsc.li/rsc-advances

RSC Advances

ARTICLE

La-Mg mixed oxide as highly basic water resistant catalyst for utilization of CO_2 in the synthesis of quinazoline-2,4(1*H*,3*H*)-dione

Received 00th January 2016,
Accepted 00th January 2016

DOI: 10.1039/x0xx00000x

www.rsc.org/

Kalidas B. Rasal, Ganapati D. Yadav*

Synthesis of quinazoline-2,4(1*H*,3*H*)-dione was done by direct utilization of CO_2 in cyclization with 2-aminobenzonitrile using lanthanum magnesia mixed oxide (La-Mg MO) as a strong basic catalyst under mild reaction conditions in water. It gave conversion ~ 92 % with 100 % selectivity at 140 °C in 14 h. La-Mg MO was prepared by hydrothermal method using urea as a homogeneous precipitating agent. The catalyst was characterized by different analytical techniques like BET, XRD, FT-IR, SEM, TGA and basicity by CO_2-TPD and acidity by NH_3 TPD. Various reaction parameters were studied to predict reaction mechanism and kinetics. The reaction follows the Langmuir-Hinshelwood Hougen-Watson (LHHW) type kinetic model with apparent activation energy (18.3 kcal/mol). The catalyst was recycled for three times with an insignificant change in activity.

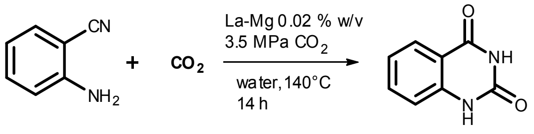
Introduction

Global warming is the outcome of anthropogenic emission of greenhouse gasses. The recent reports show the main reason for increasing CO_2 level is the increasing energy demand (i.e. burning fossil fuel).[1,2] CO_2 is abundantly available, non-toxic, non-flammable, a renewable carbon source and so on.[3,4] CO_2 utilization as the C1 source is an elegant approach to synthesize several value-added chemicals like methanol, formic acid, DMC, syngas, etc.[5–8] Also provides the best alternative to highly toxic carbon monoxide and phosgene.[9,10] CO_2 is utilized for the synthesis of organic carbonates,[11] reduction to hydrocarbon,[12,13] carbonylation reactions [14] and methane reforming.[15]

Quinazoline-2,4(1*H*,3*H*)-dione (quinazolinedione) and its derivatives are conversadly used as key building blocks in the pharmaceutical industry for the synthesis of antihypertensive, antidiabetics, heart disease and other important medicines.[16] The green chemistry point of view synthesis of quinazolinedione using CO_2 as a C1 source has achieved great importance. Several heterogeneous catalytic systems were developed to synthesize quinazolinedione using 2-aminobenzonitrile (2ABN) and CO_2 as common starting materials such as; MgO/ZrO_2,[17] tungsten oxide,[18] mesoporous smectites,[19] amine fictionalize MCM-41,[20] [Hmim]OH supported on SiO_2,[21] TBD supported on Fe_3O_4[22] and amide supported on the polymer.[23] Also ionic liquids and organic bases such as; [Bmim]OH,[24] [TBP][Arg],[25] $[HDBU^+][TFE^-]$,[26] reversible IL (DBU based),[27] [Bmim]Ac,[28] DBU,[29] guanidine base,[30] DBU as catalyst in $ScCO_2$ (solvent and reactant),[31] N-heterocyclic carbene (NHC) with K_2CO_3[32] and $CsCO_3$,[33] were reported. These methods have common drawbacks like the use of organic solvents, low atom economy and use of costlier reagents.

Recently, Ma *et.al.*[34] developed catalyst free synthesis of quinazolinedione in water, (160°C, 14 MPa of CO_2 pressure for 21 h) it works at harsh reaction condition. To overcome these difficulties herein, we report the comparatively simple synthesis of quinazolinedione in water using lanthanum magnesia mixed oxide (La-Mg MO) as catalyst **(Scheme 1)**. La-Mg MO was previously used as strong base catalyst in synthesis of cyclic carbonate,[35] Wittig reaction[36] and aldol reaction.[37]

In CO_2 utilization pathways, the main challenge is activation of CO_2 due to its low reactivity. In this perspective, we report the use of La-Mg MO as a basic catalyst in the synthesis of quinazolinedione using water as a solvent. The catalyst was previously characterized by different analytical techniques; XRD, FT-IR, CO_2 and NH_3-TPD, BET surface area and TGA before and after use. The reaction mechanism and kinetics were studied.



Scheme 1: Synthesis of quinazolinedione by coupling of 2ABN and CO_2.

---

[a] **Department of Chemical Engineering, Institute of Chemical Technology (ICT), Nathalal Parekh Marg, Matunga (E), Mumbai - 400 019, INDIA.*
[b] *E-mail: gdyadav@gmail.com, gdyadav@yahoo.com*
[c] *Tel: +91-22-3361-1001/1111/2222,*
[d] *Fax: +91-22-2414-1002/1020*

† Electronic Supplementary Information (ESI) available: [details of any supplementary information available should be included here]. See DOI: 10.1039/x0xx00000x

Table 1: Literature review for synthesis of Quinazoline-2,4(1*H*,3*H*)-diones

Sr. no.	solvent	Catalyst used	Temp. (°C)	Time (h)	CO2 Pressure (MPa)	% conversion	Reference no.
1	solventless	ReIL	40	15	0.1	98	27
2	solventless	[Bmim]OH	120	18	3.0	90	24
3	solventless	[HDBU][TFE]	30	24	0.1	97	26
4	solventless	[Bmim]Ac	90	10	0.1	92	28
5	DMF	MgO/ZrO_2	130	12	3.7	92	17
6	DMF	$TBD@Fe_3O_4$	140	16	4.0	64	22
7	DMF	DBU, DBN (3 eq. base)	20	24	0.1	97	29
8	DMF	Mesoporous smectites	130	6	4.0	68	19
9	DMF	[TBP][Arg]	100	12	8.5	92	25
10	DMSO	NHC, K_2CO_3	120	15	0.1	95	32
11	NMP	$TBA_2[WO_4]$	140	24	2.0	91	18
12	ScCO2	DBU (0.05 eq.)	80	4	10	89	31
13	Water	-	160	21	14	92	34
14	Water	Amine functionalize MCM-41	130	18	3.5	91	20
15	Water	La-Mg Mixed oxide	140	14	3.5	92	Current work

Results and discussion

La-Mg MO

Kantam et.al.[36] reported that La-Mg MO of 1:3 molar ratio (La:Mg) shows the highest basicity. Conventionally, La-Mg MO was synthesized by co-precipitation method at constant pH (9-10) using nitrate precursors and NaOH or ammonia as precipitating agent.[36,38] We prepared La-Mg MO with the hydrothermal method, using urea hydrolysis as a source ammonia.

Role of urea in synthesis of La-Mg MO

The urea hydrolysis technique used to get mono-dispersed nano-sized metal oxides.[39–42] In this method controlled hydrolysis of urea supplies ammonium hydroxide and carbonate at decomposition temperature of urea, which promotes the precipitation of metal ion to hydroxides, carbonates, and oxyarbonates with uniform size.[43] The metal nitrate to urea mole ratio was studied in a range of 1 : 0.5 to 1 : 4. It was found that the surface area of La-Mg MO increases significantly from 1 : 0.5 to 1 : 2 and thereafter decreases with increase in urea concentration. So, the concentration of urea has significant effect on the surface properties of the catalyst, which is studied by BET surface area analysis. The 1:2 (nitrate: urea) shows highest surface area (78.25 m^2/g) (**Table-1**). The pH value substantially increases with increase in urea concentration. Therefore at a lower concentration of urea, there was incomplete precipitation.[44,45] At higher pH the nucleation process of the metal hydroxide is very high. Due to more concentration of ammonium hydroxide, the nuclei of metal hydroxide and OH^- ions get attracted to each other with hydrogen bonding. The strong hydrogen bonding is responsible for formation of agglomeration in metal hydroxide particles, which results in low surface area of catalyst.[46]

Catalyst characterization

XRD

XRD patterns of catalysts were analyzed in the range of 10°-75° 2θ value. La_2O_3, MgO, and La-Mg mixed oxide catalysts show sharp peaks (**Figure 1**). The peaks observed at a 2θ value of 25.21°, 30.54°, 46.34° and 55.76° are due to (100), (101), (110) and (201) planes of $La_2O_2CO_3$ and La_2O_3, respectively (JCPDS card # 49-0981).[47] The peaks observed 2θ at 42.3 and 62.4 confirm the crystalline phase of MgO (JCPDS data card # 45-946).[48]

In case of La-Mg MO peaks related to the different phases of La_2O_3 and $La_2O_2CO_3$ are clearly observed and MgO phases are nearly disappeared.[49,50] Thus, it shows well dispersion of lanthanum on MgO.

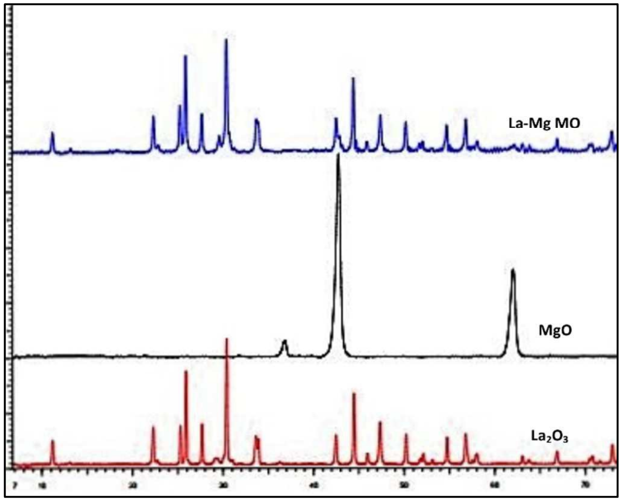


Figure 1: X- ray diffraction pattern of (a) La-Mg mixed oxide (b) MgO and (c) La_2O_3

The reused catalyst does not show any significant change in XRD patterns even after third reuse (ESI† Figure S3). It confirms the structural stability of the catalyst.

Morphology of catalyst (SEM)

Pure La_2O_3 shows nanocluster formation due to agglomeration of La_2O_3 nanoparticles. La-Mg mixed oxide forms a dendritic and spherical like structure and MgO show spherical structure. The reused catalyst shows a change in morphology due partial rehydration (memory effect) in the reaction **(Figure 2)**.

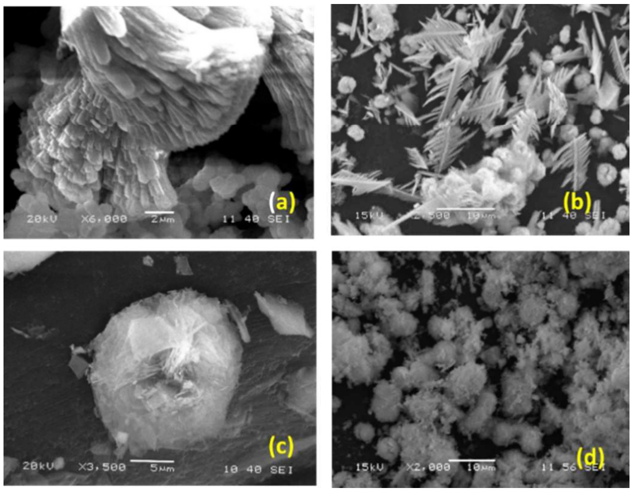


Figure.2: SEM images of (a) La_2O_3, (b) La-Mg MO and (c) MgO and (d) reused La-Mg MO

BET surface area

La-Mg MO shows the type IV adsorption isotherm corresponding to the mesoporous structure. La-Mg MO (1:2; nitrate: urea ratio) shows high surface area compared to other ratios as described above **(Table 1)**. The surface area of pure La_2O_3 and MgO are 19.3 and 99.2 m^2/g, respectively whereas La-Mg MO shows 78.2 m^2/g. The increase in surface area of La-Mg MO shows the dispersion of lanthanum on the surface of MgO.

Acidity and basicity of catalyst

CO_2 and NH_3-TPD analyses were performed to measure basicity and acidity of catalysts, respectively. La-Mg MO shows 0.78 mmol/g and pure La_2O_3 shows 0.28 mmol/g, the surface area of La-Mg MO increase significantly due to well the dispersion of La_2O_3 on MgO[51] **(Table 1)**. According to the previous published report,[52] the CO_2 desorption was divided into three regions, i.e. weak basic (50 to 150°C), moderately basic (200 to 400°C) and strong basic (more than 400°C). The CO_2 TPD of catalyst shows two desorption peaks at 198 and 347°C. The desorption of peak associated with 198°C shows weak basic sites (0.37 mmol/g) and peak at 347°C attributed to the desorption of CO_2 from moderately basic sites (0.41 mmol/g). The NH_3-TPD of La-Mg MO shows the mild acidity (0.18 mmol/g). The reused La-Mg MO shows nearly the same basicity (0.73 mmol/g) as compared to fresh catalyst.

FT-IR

Figure 3 shows absorbance bands at about 642 and 450 cm^{-1} which are related to lattice vibration modes due to La-O bond. The band at 1085 cm^{-1} is weak but sharp and observed due to symmetric $(CO_3)^{2-}$. Weak bands are seen at 1750 and 1832 cm^{-1}. The 1750 cm^{-1} may be due to carbonyl group of carbonate and

1832 cm^{-1} due to bridged carbonate containing metal-oxygen bond.[50] The peak observed at 642 and 450 cm^{-1} which are related to lattice vibration due to La-O bond. The individual FT-IR spectra provided in ESI.

Table 2: surface area, pore size, pore volume and basicity of catalyst

Sr. no.	catalyst	nitrate to urea mole ratio	CO_2 TPD (mmol/g)	surface area (m^2/g)	pore size (nm)	pore volume (cm^3/g)	pH of supernatant water
1	La-Mg MO	1:0.5	0.29	28.6	7.8	0.21	8.0
2	La-Mg MO	1:1	0.45	52.3	8.5	0.25	8.5
3	La-Mg MO	1:2	0.79	78.2	8.7	0.24	9.6
4	La-Mg MO	1:3	0.56	62.4	9.8	0.11	10.5
5	La-Mg MO	1:4	0.36	51.2	11.9	0.10	11.8
6	La_2O_3	1:2	0.29	19.3	24.0	0.12	-
7	MgO	1:2	0.39	99.2	6.9	0.17	-
8	La:Mg (co-ppt)	-	0.52	37.2	12.1	0.23	-
9	La:Mg (reuse)	1:2	0.73	73.5	7.9	0.21	-

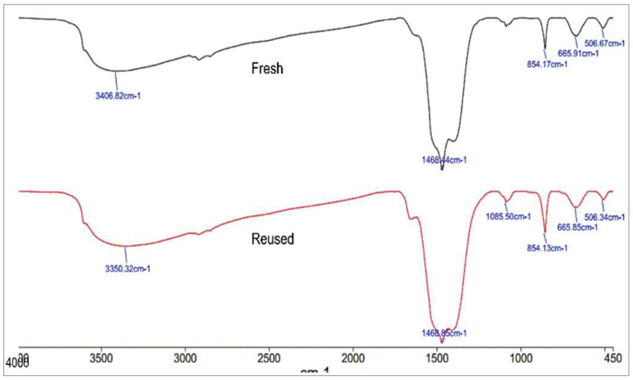


Figure 3: FT-IR of fresh and reused La-Mg mixed oxide

TGA

Thermal stability of calcined, uncalcined and reused La-Mg MO (without calcined) catalysts were studied by TGA **(Figure 4)**. Fresh La-Mg MO does not show a considerable loss in weight, due to the formation of stable oxide form. The reused and uncalcined La-Mg MO shows nearly the same TGA curve that indicates that La-Mg MO shows memory effect like LDH.[53,54] In uncalcined and reused La-Mg MO shows that 1-2 % loss in weight due to a loss of water (humidity) at 100°C. 5-6 % Loss at 320 to 380°C indicates that decomposition of metal oxycarbonates and evolution of CO_2 to get stable oxide forms. The carbonate content of reused catalyst is 6-7 %.[55] Thereafter there is no significant loss in weight which shows the formation of stable oxide forms.

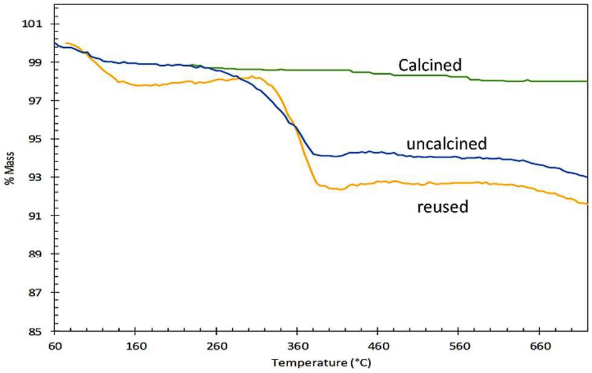


Figure. 4: TGA of La-Mg MO (a) calcined, (b) uncalcined and (c) reused catalyst

XPS

Figures 5 and **6** show the XPS spectra of fresh and reused La-Mg MO. The survey spectra show signals for La and Mg. For La_2O_3 it shows high-resolution La $3d_{5/2}$ and La $3d_{3/2}$, XPS peaks observed at 835.37 and 852.41 eV with a spin-orbit splitting 17.02 eV and for reused La-Mg MO spin-orbital splitting is 17.56 eV. Splitting of La $3d_{5/2}$ attributes to the formation of hydroxide and BE is 835.41 indicates formation of carbonate phase in the catalyst. This is observed due to adsorption moisture and atmospheric CO_2 on the surface of the catalyst. A sharp O 1s was observed at 530.1 eV as prepared the samples. Due to MgO, the peak observed for Mg 2s at 89.3 and 88.9 eV for fresh and reused catalyst, respectively. The peak observed at 1304 eV due to MgO in both fresh and reused catalyst. [56]

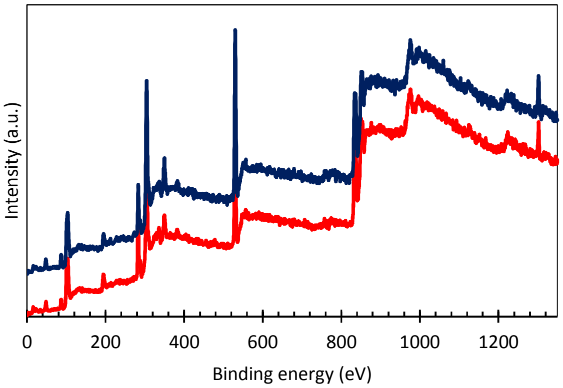


Figure 5: Survey spectra of La-Mg Mo

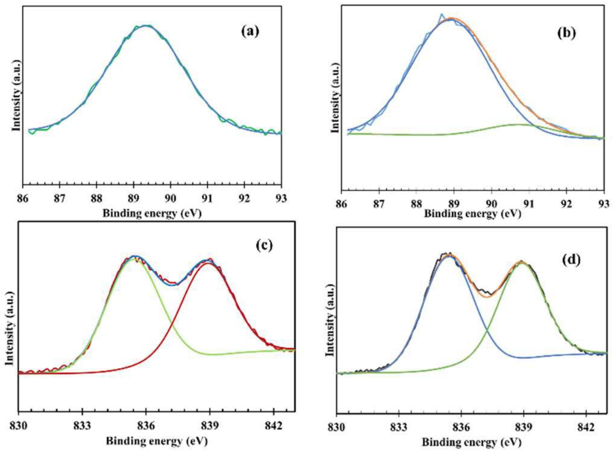


Figure 6: XPS of La-Mg MO; (a), (b) and (c), (d) XPS spectra of Mg 2s and La 3d3/2 fresh and reused catalyst, respectively.

Reaction parameter study

Catalyst screening

The prepared catalyst was studied for its activity in utilisation of CO_2 in quinazolinedione synthesis. It was shown in **Table 3**. La-Mg MO (hydrothermal method) gives good conversion as compared to MgO, La_2O_3 and La-Mg by co-precipitation method.

Table 3: Catalyst screening study

catalyst used	% conversion
La_2O_3 (commercial)	28.2
La_2O_3	46.2
MgO	28.4
La-Mg MO (hydrothermal)	92.1
La-Mg MO (co-ppt)	76.8

CO_2 pressure study

CO_2 pressure was varied in a range of 0.5 to 4.5 MPa to study its influence on the conversion of quinazolinedione. CO_2 pressure increases H_2CO_3 concentration in water so there is a significant increase in conversion with an increase in pressure up to 3.5 MPa. Thereafter, the conversion is nearly the same with an increase in CO_2 pressure **(Figure 7)**. It is due to, this system is three-phase i.e. gas (CO_2), liquid (water as solvent) and solid (catalyst). Since the CO_2 pressure was maintained throughout the reaction, so the concentration of H_2CO_3 remains constant. There is an equilibrium in between CO_2 and water, so transfer of H_2CO_3 to the catalyst surface for its activation.[57–59] The concentration of H_2CO_3 is much higher than required after 3.5 MPa pressure, which was adsorbed on the surface of the catalyst, therefore no significant change in conversion was observed at a constant temperature.[60] Also, at high CO_2 pressure the equilibrium of adoption and desorption of reactant and product may get disturbed.

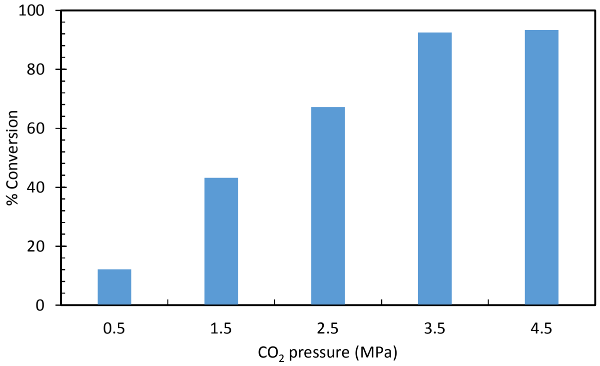


Figure 7: Effect of pressure on synthesis of quinazolinedione; Reaction conditions:2-ABN (5 mmol), La-Mg MO (0.02 % (w/v)), reaction time (14 h), reaction temperature (140°C), 30 mL water

Speed of agitation

A speed range from 800 to 1000 rpm was studied for mass transfer resistance. After 1000 rpm the conversion is practically same. It confirms that there is no mass transfer resistance effect after 1000 rpm conversion. Hence, 1000 rpm was chosen to completely remove mass transfer resistance **(Figure 8)**

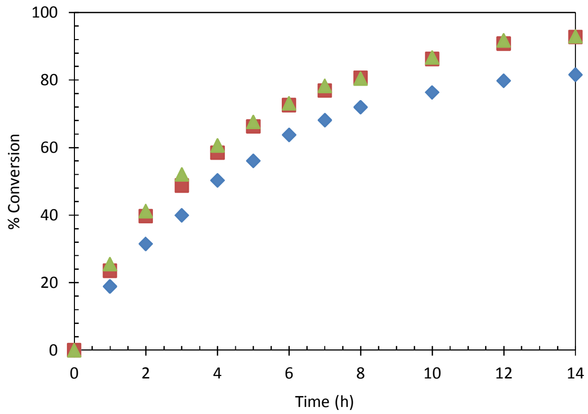


Figure 8: Speed of agitation for synthesis of quinazolinedione; Reaction conditions: 2ABN (5 mmol), La-Mg MO (0.02% (w/v)), CO2 pressure (3.5 MPa), reaction time (14 h), reaction temperature (140°C), 30 mL water

Effect of catalyst loading

Catalyst loading was studied in the range of 0.01 to 0.03 g/cm^3 w.r.t. reaction volume, keeping all other reaction conditions constant **(Figure 9)**. Up to 0.02 g/cm^3 of catalyst loading, there was a significant increase in conversion due to proportionally increase in active sites of catalyst available for reaction. However, after 0.02 $g/cm^{3,}$ there are no significant increases in conversion. It is due to the availability of more active sites for reaction. Hence, even increase in catalyst loading from 0.02 g/cm^3 the conversion does not increase with catalyst loading.

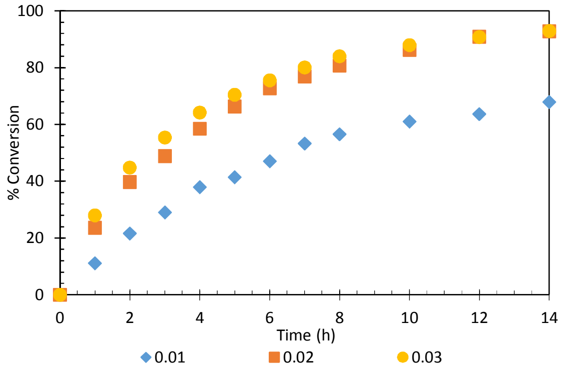


Figure.9: Effect of catalyst loading on synthesis of quinazolinedione; Reaction conditions: 2ABN (5 mmol), reaction time (14 h), CO2 pressure (3.5 MPa), reaction temperature (140°C), 30 mL water

Effect of initial concentration of 2ABN

The initial concentration of 2ABN was varied from 0.1 to 0.2 $mmol/cm^3$ keeping all other reaction parameters constant **(Figure 10)**. With this decrease in concentration the rate of reaction increases linearly up to 0.16 $mmol/cm^3$, thereafter there is no significant increase in the rate of reaction. However, with 0.16 $mmol/cm^3$, we got good conversion hence it has been selected for further study.

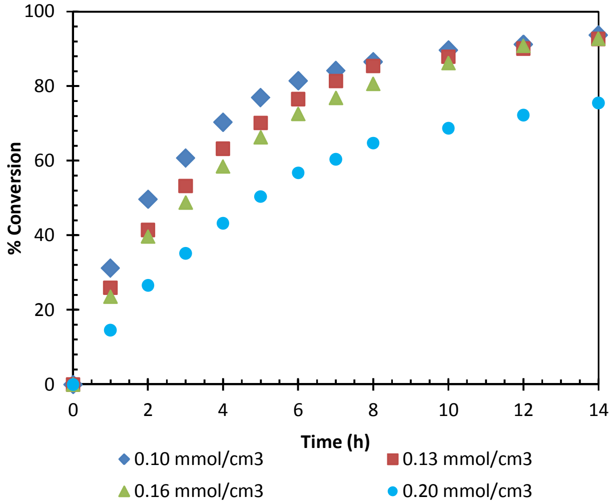


Figure10: Effect of initial moles of 2ABN on the synthesis of quinazolinedione; Reaction conditions: CO2 pressure (3.5 MPa), La-Mg MO (0.02% (w/v)), reaction temp. (140°C), reaction time (14 h), 30 mL water

Effect of temperature

Effect of temperature on the rate of reaction was studied from 120 to 150°C. The rate of reaction increases substantially with increases with temperature which show that the reaction is kinetically controlled. **(Figure 11)**. The detailed study discusses again in kinetics part.

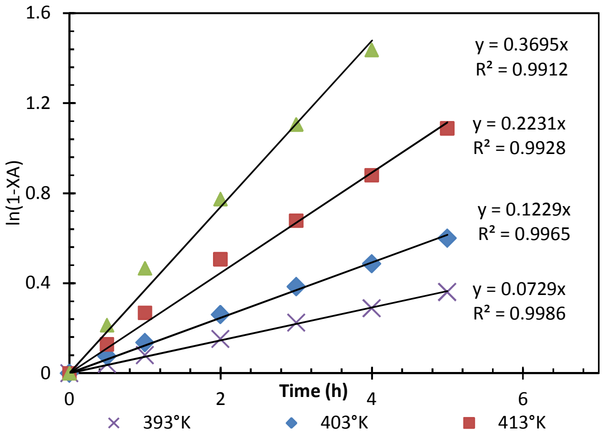


Figure11: Plot of ln(1-X_A) vs time (h)

Reusability of catalyst

After completion of reaction the reaction mass was filtered and the catalyst was washed 3-4 times with methanol to remove adsorbed 2ABN and quinazolinedione. Then it was dried at 105°C for 12 h. The reusability of catalyst was studied for three cycles. The initial rate constants of cyclization of 2ABN and CO_2 was calculated **(Table 4)**. The rate constant values are comparably same, indicates that catalyst is reusable. The % conversion vs time was shown in **Figure 12**. Reused catalyst was well characterized by common analytical techniques. Reused catalyst shows slight changes in surface area, pore size, pore volume and basicity of the catalyst **(Table-2)**.

For reusability study, the leaching test of catalyst was performed to check leaching La-Mg MO catalyst. It was observed that; 5.8 ppm and 1.8 ppm of MgO and La_2O_3 leaching, respectively. In water La and Mg oxides get hydrolyse, thus there is slight leaching was observed during the course of the reaction. The leaching is very less because the MgO and La_2O_3 phase have very less solubility in water.

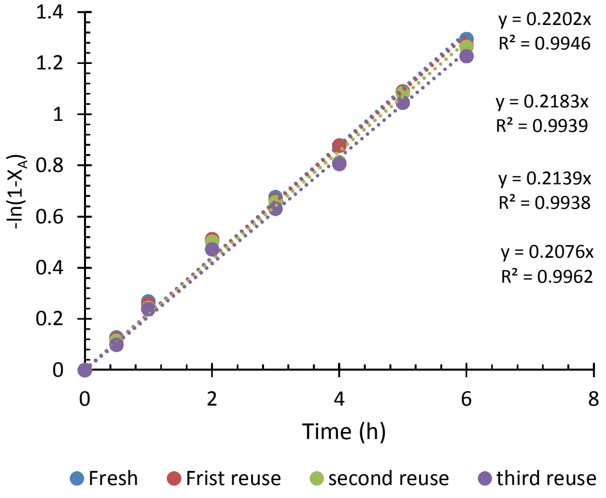


Figure.12. Reusability of the La-Mg Mixed oxide for the synthesis of quinazolinedione; Reaction conditions: 2-ABN (5 mmol), CO_2 pressure (3.5 MPa), La-Mg MO (0.02% (w/v)), reaction time (14 h), reaction temp. (140°C), 30 mL water solvent

Table 4: initial rates for reusability of La-Mg MO

Catalyst La-Mg MO	Rate constants (lit/g cat/atm/h)
Fresh	0.2202
Frist reuse	0.2183
Sec. reuse	0.2139
Third reuse	0.2076

Substrate study of 2ABN

The optimized reaction conditions were used to extend the scope of reaction with CO_2 using La-Mg MO as a catalyst. Substrate with different electron--donating and withdrawing group were studied **(Table 5)**. 2ABN derivatives with an electron-withdrawing group (-NO_2, -Cl and -F) give higher conversion as compared to electron-donating groups (-CH_3 and -OMe).

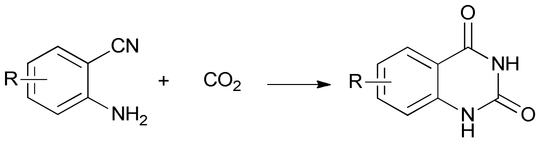
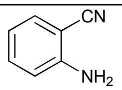
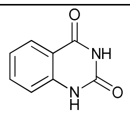
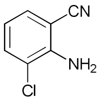
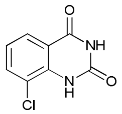
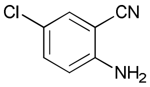
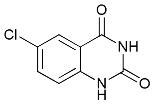
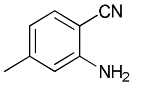
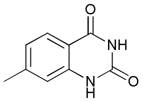
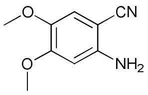
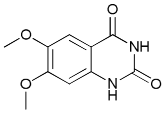
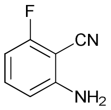
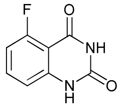
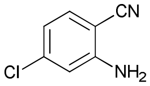
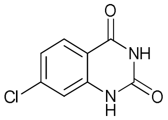
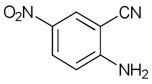
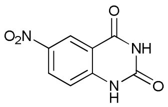


Table 5: Substrate scope of quinazoline-2,4(1H,3H)-dione

Sr no.	substrate	product	% conversion
1			92.3
2			82.8
3			86.8
4			91.5
5			93.3
6			75.9
7			89.2
8			84.6

Reaction conditions: 2ABN (5 mmol), CO_2 pressure (3.5 MPa), reaction temperature (140°C), solvent (30 mL), La-Mg mixed oxide 0.02% (w/v), reaction time (14 h), (a): isolated yield.

NMR data;

1. **Quinazoline-2,4(1*H*,3*H*)-dione** (Table 5 (1))
^{1}H NMR: *δ* = ^{1}H NMR (500 MHz, DMSO-D$_6$) *δ* 11.27 (s, 1H), 11.12 (s, 1H), 7.86 (d, *J* = 7.4 Hz, 1H), 7.60 (t, *J* = 7.3 Hz, 1H), 7.15 (t, *J* = 7.3 Hz, 2H); *^{13}C NMR* (126 MHz, DMSO D$_6$) *δ* 163.27 (s), 150.74 (s), 141.27 (s), 135.37 (s), 127.37 (s), 122.75 (s), 115.74 (s), 114.74 (s).

2. **5-Chloroquinazoline-2,4(1*H*,3*H*)-dione** (Table 5 (2))
^{1}H NMR (500 MHz, DMSO) *δ* 11.23 (t, *J* = 20.7 Hz, 2H), 7.52 (dd, *J* = 11.8, 4.3 Hz, 1H), 7.20 – 7.15 (m, 1H), 7.10 (dd, *J* = 8.3, 0.9 Hz, 1H); *^{13}C NMR* (126 MHz, DMSO) *δ* 161.24 (s), 150.07 (s), 143.96 (s), 135.11 (s), 134.24 (s), 125.48 (s), 115.18 (s), 111.59 (s).

3. **6-Chloroquinazoline-2,4(1*H*,3*H*)-dione** (Table 5 (3))
^{1}H NMR (500 MHz, DMSO) δ 11.54 (s, 1H), 11.37 (s, 1H), 7.89 (dd, *J* = 6.7, 2.5 Hz, 1H), 7.80 – 7.72 (m, 1H), 7.31 – 7.23 (m, 1H); *^{13}C NMR* (126 MHz, DMSO) *δ* 162.25 (s), 150.47 (s), 140.13 (s), 135.23 (s), 126.72 (s), 126.33 (s), 117.94 (s), 116.19 (s).

4. **7-Methylquinazoline-2,4(1*H*,3*H*)-dione** (Table 5 (4))
^{1}H NMR (500 MHz, DMSO) *δ* 11.18 (s, 1H), 11.06 (s, 1H), 7.74 (dd, *J* = 7.9, 3.1 Hz, 1H), 7.02 – 6.84 (m, 2H), 2.32 (s, 3H); *^{13}C NMR* (100 MHz, DMSO-d6) δ 163.15, 150.89, 146.06, 141.33, 127.33, 124.11, 115.48, 112.44, 21.86.

5. **6,7-Dimethoxyquinazoline-2,4(1*H*,3*H*)-dione** (Table 5 (5)) *^{1}H NMR* (400 MHz, DMSO-d6) *δ* =11.09 (s, 1H), 10.94 (s, 1H), 7.21 (s, 1H), 6.62 (s, 1H), 3.89 (s, 3H), 3.65 (s, 3H).
^{13}C NMR (100 MHz, DMSO-d6) δ = 162.86, 155.31, 150.88, 145.44, 136.95, 107.52, 106.6, 98.17, 56.17(2C).

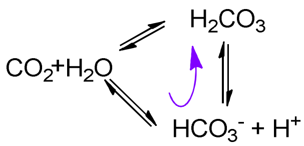
6. **5-Fluoro-1H-quinazoline-2,4(1*H*,3*H*)-dione** (Table 5 (6))
^{1}H NMR (400 MHz, DMSO) *δ* = 10.91(s, 1H), 10.91 (s, 1H), 7.31 (m, 1H), 6.14 (m, 2H); *^{13}C NMR* (d6-DMSO) δ 166.28, 151.76, 150.38, 142.95, 135.90, 102.9, 100.72, 97.89.

7. **7-Chloro quinazoline-2,4(1*H*,3*H*)-dione** (Table 5 (7))
^{1}H NMR (400 MHz, DMSO) *δ* = 11.39 (s,1H), 11.24 (s, 1H), 7.86 (d,1H), 7.20 (d, 1H), 7.16 (s, 1H); *^{13}C NMR* (d6-DMSO) δ 162.53, 150.61, 142.39, 139.72, 129.47, 122.93, 115.11, 113.76.

8. **6-Nitro quinazoline-2,4(1*H*,3*H*)-dione** (Table 5 (8))
^{1}H NMR (400 MHz, d6-DMSO) *δ* = 11.73 (s, 2H), 8.44(d, 1H), 8.37(t, 1H), 7.30(d, 1H); *^{13}C NMR* (d6-DMSO) δ 162.13, 150.59, 146.10, 142.29, 129.32, 123.55, 116.30, 115.41.

Possible reaction mechanism

The reaction mechanism for the synthesis of quinazolinedione by condensation of 2ABN with CO_2 using La-Mg MO is proposed as shown in **Figure 13**. Chemical interaction of water and CO_2 forms H_2CO_3, this formation and decomposition of H_2CO_3 through bicarbonate ion as an intermediate.[61–63] The CO_2, HCO_3^- and H_2CO_3 is in equilibrium by Eigen's triangular scheme. The catalyst used La-Mg MO is basic in nature so there is the possibility of adsorption of H_2CO_3 on the surface of catalyst.



Due to the basicity of catalyst the H_2CO_3 (mild acid) get adsorbed on the basic site of the of catalyst surface and CO_2 molecule get activated.

Basicity of 2ABN is too low (pKa = 0.77) and also the H_2CO_3 is weak acid, therefore direct attack of H_2CO_3 on amine group of 2ABN is not feasible. Therefore, the H_2CO_3 hydrolyses -CN group. This reaction shows a similar type of mechanism pathway as previously reported literature i.e. without catalyst synthesis of quinazolinedione in water.[34,64] Main difference is the use of a catalyst to minimizes the activation energy of CO_2.

Kinetics

In the absence of mass transfer and intraparticle diffusion resistance, the reaction seems to be kinetically controlled. The reaction was supposed to occur by LHHW with dual site mechanism. To prove this we have developed a mathematical model to calculate different constants and thus calculated the activation energy for the reaction.[65–68] Considering the reaction between 2ABN (A) and CO_2 (B) happens on the catalyst surface and A will chemisorb on the S_a (acidic) and B (carbon dioxide) will adsorb on S_b (basic) catalyst site.

For general chemical reaction;

$$A + B \rightarrow C$$

Adsorption of 2ABN (A) and carbon dioxide (B) on catalyst sites is given by,

$$A + S_a \xleftrightarrow{K_a} A.S_a \qquad (1)$$

$$B + S_b \xleftrightarrow{K_B} B.S_b \qquad (2)$$

Surface reaction of AS and BS on catalyst site, there is formation of CS,

$$A.S_a + B.S_b \xleftrightarrow{k_1} C.S_a + S_b \qquad (3)$$

Rate of desorption of quinazolinedione (C) is given by,

$$C.S_a \xleftrightarrow{1/K_C} C + S_a \qquad (4)$$

The overall rate of reaction is as follows;

$$rate(-r_A) = k_1 C_{A.S_a} C_{B.S_b} - k'_1 .C_{C.S_a} .C_{S_b} \qquad (5)$$

Site balance

$$C_{AS_a} = K_A .C_A .C_{Sa} \qquad (6)$$

$$C_{B.S_b} = K_B .p_B .C_{S_b} \qquad (7)$$

RSC Advances

ARTICLE

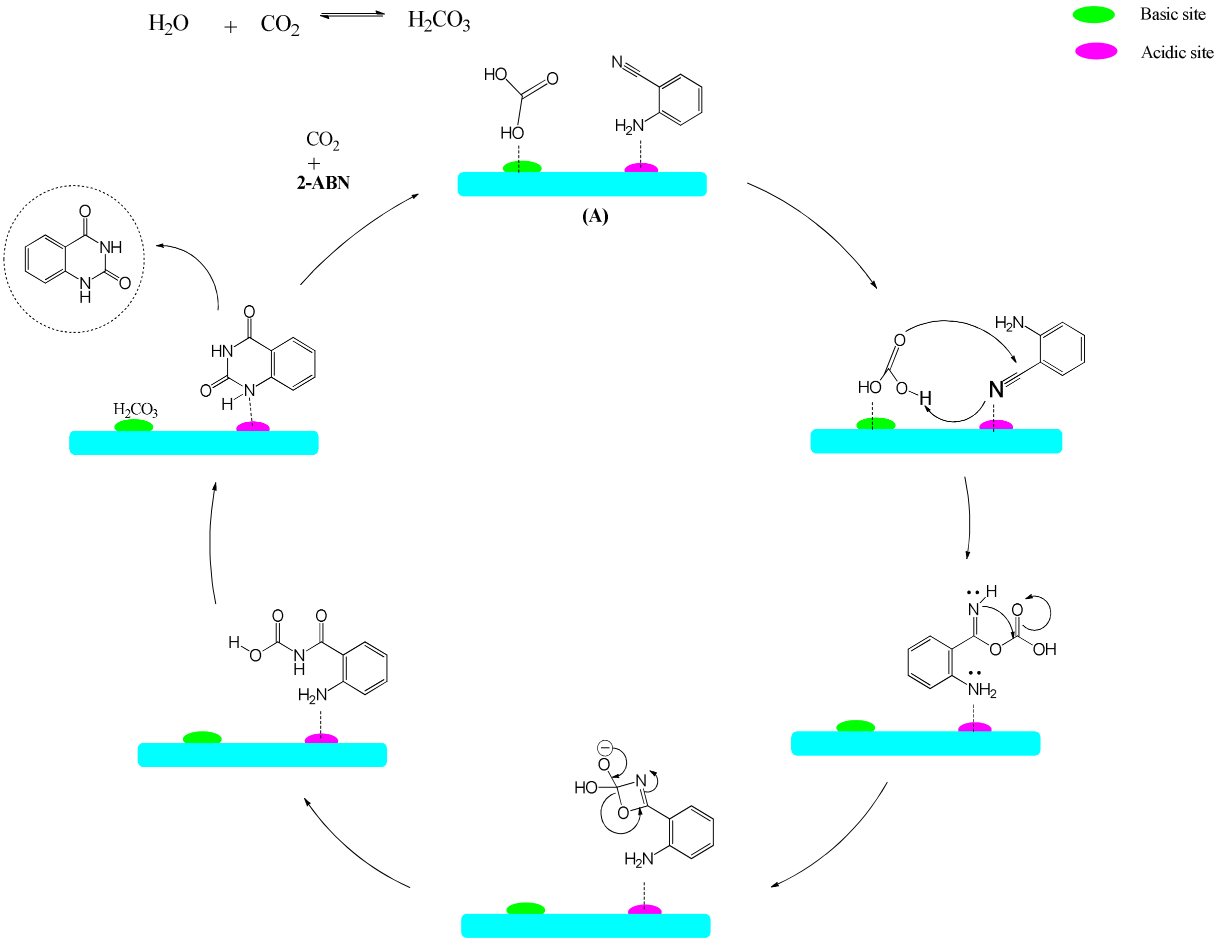


Figure 13: Possible mechanism for synthesis of quinazolinedione

$$C_{C.Sa} = K_C.C_C.C_{S_a} \qquad (8)$$

The total concentration of the sites is;

For acidic sites,

$$C_{t_a} = C_{A.S_a} + C_{C.S_a} + C_{S_a} \qquad (9)$$

$$C_{t_a} = K_A.C_A.C_{S_a} + K_C.C_C.C_{CS_a} + C_{S_a}$$

$$C_{t_a} = (K_A.C_A + K_C.C_C.+1)C_{S_a}$$

$$C_{S_a} = \frac{C_{t_a}}{(1+K_A.C_A+K_C.C_C.)} \qquad (10)$$

For basic sites,

$$C_{t_b} = C_{B.S_a} + C_{S_b}$$

$$C_{t_b} = (K_B.p_B.C_{S_b} + C_{S_b})$$

$$C_{t_b} = (1+K_B.p_B).C_{S_b}$$

$$C_{S_b} = \frac{C_{t_b}}{(1+K_B.p_B)} \qquad (11)$$

$$rate=\frac{-dC_A}{dt}=k_1K_AC_{A.}C_{S_a}.K_B.p_{B.}C_{S_b}-k_1^{'}K_CC_{C.}C_{S_a.}C_{S_b} \quad (12)$$

From Equation 10, 11 and 12 we have

$$-r_{A_i}=\frac{-dC_A}{dt}=\frac{k_1.K_A.K_B.C_A.p_B.C_{t_a}.C_{t_b}-k_1^{'}K_CC_{C.}C_{t_a.}C_{t_b}}{(1+K_A.C_A+K_C.C_C)(1+K_B.p_B)} \quad (13)$$

For initial rate of reaction, we can write above equation as;

$$-r_{A_i}=\frac{-dC_A}{dt}=\frac{k_1.K_A.K_B.C_A.p_B.C_{t_a}.C_{t_b}}{(1+K_A.C_A)(1+K_B.p_B)}$$

Consider, $k_1.C_{t_a}.C_{t_b}=k'w$

$$-r_{A_i}=\frac{-dC_A}{dt}=\frac{k'.w.K_A.K_B.C_A.p_B}{(1+K_A.C_A)(1+K_B.p_B)} \quad (14)$$

By solving this equation with Solver we have calculated rate constant and adsorption constant for 2-aminibenzonitrile and carbon dioxide as per given in **Table 6** below,

Table 6: adsorption constants

Temperature (°K)	Rate constant(k) (cm^3/g-cat/atm/h)	Adsorption constant (K_A) (cm^3/mol)	Adsorption constant (K_B) (atm^{-1})
393	0.028937	1.635	0.0045
403	0.060757	1.510	0.0042
413	0.120673	1.420	0.0039
423	0.239943	1.390	0.0035

The activation energy was calculated by Arrhenius equation; the apparat activation energy is found to be 23.3 kcal/mol (**Figure 14**)

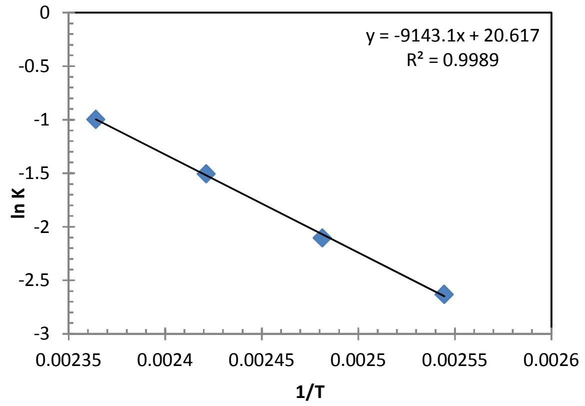


Figure14: Plot of ln k vs 1/T

Experimental

Chemicals

Urea, $La(NO_3)_3.6H_2O$ and $Mg(NO_3)_2.6H_2O$ were supplied by S. D. fine chemicals, Mumbai, India. 2ABN (purity >98%) and all related compounds were supplied by Sigma-Aldrich. All chemicals used as such without further purification. CO_2 gas (Purity 99.99%) purchase from Rakhangi Mumbai.

Preparation of La-Mg MO

0.015 mmol $Mg(NO_3)_2.6H_2O$ and 0.005 mmol $La(NO_3)_3.6H_2O$ (mole ratio La/Mg = 1:3) were dissolved in 150 mL distilled water. Then, 0.09 mol urea was added (nitrate to urea ratio 1:2) into the above solution, which was agitated at 30°C for 30 min. After that solution was transferred to a teflon lining bomb reactor and kept at 433°K for 24 h then cool it naturally at room temperature. Then, the precipitate was filtered and washed multiple times with distilled water up to neutral pH. Then it dried at 373°K in the oven for 12 h and further calcined at 923°K at a ramp rate of 2 °K/min in the presence of air for 4 h and store in air tight container. Similarly, the La_2O_3 and MgO also prepared by using the same method used for La-Mg MO.

Synthesis of quinazolinedione

The reaction of 2ABN and CO_2 was carried out at 140°C in autoclave.[38] In this experiment, 5 mmol of 2ABN and 30 mL water were added to the autoclave and flushed 2-3 times with CO_2, to remove unwanted air. Then, the reactor was heated 140°C and pressurized with CO_2 at 3.5 MPa. The desired CO_2 pressure and the temperature were maintained throughout the experiments. The sampling was done periodically so as for check reaction progress by HPLC analysis. At end of reaction, the reactor was cooled to room temperature and then CO_2 release to the atmosphere. The product was extracted with organic solvents. The product structure was confirmed by mass and H-NMR.

Conclusion

In summary, we have successfully developed homogeneous precipitation method (urea method) for preparation of La-Mg MO. This is an efficient catalyst for synthesis quinazoline-2,4(1*H*,3*H*)-dione from the coupling of 2-ABN and CO_2. For this reaction water was used as a reaction medium; conventionally organic solvents have been used in the synthesis of quinazolinediones. The strong basicity of La-Mg MO is the reason behind the activation of CO_2. The catalyst was recycled for three times without any noticeable loss in its activity. We have developed cost-efficient and eco-friendly La-Mg MO which is highly basic water resistant recyclable catalyst.

Acknowledgements

G. D. Yadav received support from R. T. Mody distinguished Professor endowment and as J. C. Bose National Fellow from Department of Science and Technology, Government of India.

K.B. Rasal is greatly thankful to Department of Science and Technology (DST), India for financial support under 'Indo-Finnish' project and ICT (Mumbai) for providing lab facility.

References

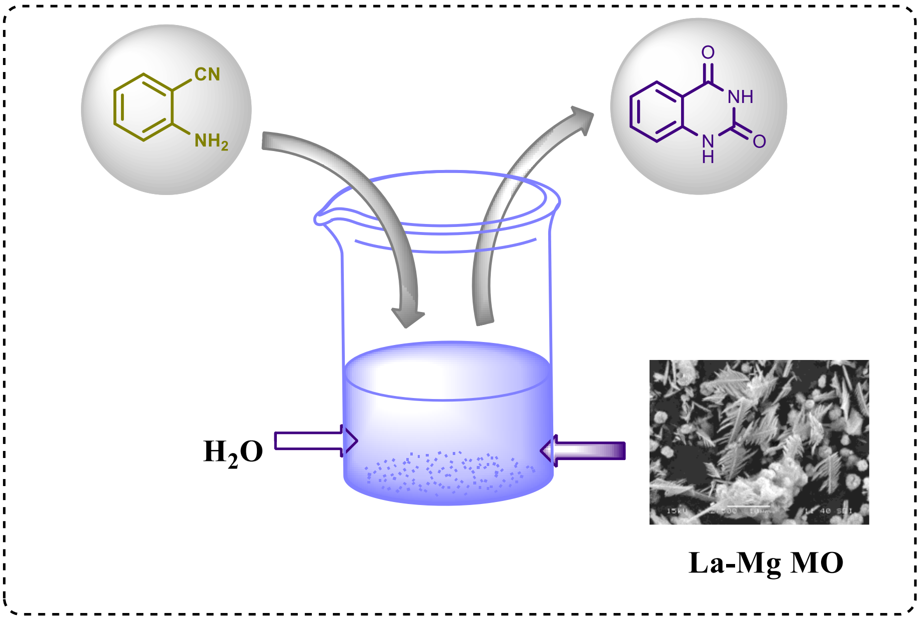
1 W. M. To, *J. Clean. Prod.*, 2015, **103**, 658–664.
2 L. Li, N. Zhao, W. Wei and Y. Sun, *Fuel*, 2013, **108**, 112–130.
3 W. Mcghee, D. Riley, K. Christ, Y. Pan and B. Parnas, *J. Org. Chem.*, 1995, **60**, 2820–2830.
4 X. Han and M. Poliakoff, *Chem. Soc. Rev.*, 2012, **41**, 1428–36.
5 N. Abas and N. Khan, *J. CO2 Util.*, 2014, **8**, 39–48.
6 H. Wang, Y. Liu, M. Li, H. Huang, H. M. Xu, R. J. Hong and H. Shen, *Optoelectron. Adv. Mater. Rapid Commun.*, 2010, **4**, 1166–1169.
7 Q. Liu, L. Wu, R. Jackstell and M. Beller, *Nat. Commun.*, 2015, **6**, 5933.
8 M. Aresta and A. Dibenedetto, *Dalton Trans.*, 2007, 2975–2992.
9 C. Maeda, Y. Miyazaki and T. Ema, *Catal. Sci. Technol.*, 2014, **4**, 1482.
10 W. Wang, S. Wang, X. Ma and J. Gong, *Chem. Soc. Rev.*, 2011, **40**, 3703–3727.
11 D. J. Darensbourg and M. W. Holtcamp, *Coord. Chem. Rev.*, 1996, **153**, 155–174.
12 L. Torrente-Murciano, D. Mattia, M. D. Jones and P. K. Plucinski, *J. CO2 Util.*, 2014, **6**, 34–39.
13 A. Goeppert, M. Czaun, J.-P. Jones, G. K. Surya Prakash and G. a Olah, *Chem. Soc. Rev.*, 2014, **43**, 7995–8048.
14 K. Huang, C.-L. Sun and Z.-J. Shi, *Chem. Soc. Rev.*, 2011, **40**, 2435–2452.
15 M. Usman and W. M. A. W. Daud, *RSC Adv.*, 2015, **5**, 21945–21972.
16 L. Jiarong, C. Xian, S. Daxin, M. Shuling, L. Qing and Z. Qi, 2009, **4**, 13–16.
17 Y. P. Patil, P. J. Tambade, K. D. Parghi, R. V. Jayaram and B. M. Bhanage, *Catal. Letters*, 2009, **133**, 201–208.
18 T. Kimura, K. Kamata and N. Mizuno, *Angew. Chemie - Int. Ed.*, 2012, **51**, 6700–6703.
19 S. Fujita, M. Tanaka and M. Arai, *Catal. Sci. Technol.*, 2014, **4**, 1563.
20 D. B. Nale, S. Rana, K. Parida and B. M. Bhanage, 2014, **4**, 0–26.
21 D. B. Nale, S. D. Saigaonkar and B. M. Bhanage, *J. CO2 Util.*, 2014, **8**, 67–73.
22 Y.-N. Zhao, B. Yu, Z.-Z. Yang and L.-N. He, *RSC Adv.*, 2014, **4**, 28941.
23 D. Nagai and T. Endo, *J. Polym. Sci. Part A Polym. Chem.*, 2009, **47**, 653–657.
24 Y. P. Patil, P. J. Tambade, K. M. Deshmukh and B. M. Bhanage, *Catal. Today*, 2009, **148**, 355–360.
25 X.-D. Lang, S. Zhang, Q.-W. Song and L.-N. He, *RSC Adv.*, 2015, **5**, 15668–15673.
26 Y. Zhao, B. Yu, Z. Yang, H. Zhang, L. Hao, X. Gao and Z. Liu, *Angew. Chemie - Int. Ed.*, 2014, **53**, 5922–5925.
27 H. Zheng, X. Cao, K. Du, J. Xu and P. Zhang, *Green Chem.*, 2014, **16**, 3142.
28 W. Lu, J. Ma, J. Hu, J. Song, Z. Zhang, G. Yang and B. Han, *Green Chem.*, 2014, **16**, 221–225.
29 T. Mizuno, M. Mihara, T. Nakai, T. Iwai and T. Ito, *Synthesis (Stuttg).*, 2007, **2007**, 2524–2528.
30 J. Gao, L. N. He, C. X. Miao and S. Chanfreau, *Tetrahedron*, 2010, **66**, 4063–4067.
31 T. Mizuno, T. Iwai and Y. Ishino, *Tetrahedron Lett.*, 2004, **45**, 7073–7075.
32 Y. Xiao, X. Kong, Z. Xu, C. Cao, G. Pang and Y. Shi, *RSC Adv.*, 2015, **5**, 5032–5037.
33 Y. P. Patil, P. J. Tambade, S. R. Jagtap and B. M. Bhanage, *Green Chem. Lett. Rev.*, 2008, **1**, 127–132.
34 J. Ma, B. Han, J. Song, J. Hu, W. Lu, D. Yang, Z. Zhang, T. Jiang and M. Hou, *Green Chem.*, 2013, **15**, 1485.
35 C. Murugan and H. Bajaj, *Indian J. Chem.*, 2013, **52**, 459–466.
36 M. L. Kantam, K. B. S. Kumar, V. Balasubramanyam, G. T. Venkanna and F. Figueras, *J. Mol. Catal. A Chem.*, 2010, **321**, 10–14.
37 M. L. Kantam, V. Balasubrahmanyam, K. B. S. Kumar, G. T. Venkanna and F. Figueras, *Adv. Synth. Catal.*, 2007, **349**, 1887–1890.
38 F. S. H. Simanjuntak, V. T. Widyaya, C. S. Kim, B. S. Ahn, Y. J. Kim and H. Lee, *Chem. Eng. Sci.*, 2013, **94**, 265–270.
39 M. Ogawa and H. Kaiho, *Langmuir*, 2002, **18**, 4240–4242.
40 H. Willard and N. Tang, *J. Am. Chem. Soc.*, 1937, 1190–1196.
41 M. Zhou, J. Yu and H. Yu, *J. Mol. Catal. A Chem.*, 2009, **313**, 107–113.
42 R. Gunawidjaja, H. Diez-y-Riega and H. Eilers, *Powder Technol.*, 2015, **271**, 255–261.
43 V. Štengl, J. Šubrt, P. Bezdička, M. Maříková and S. Bakardjieva, *Solid State Phenom.*, 2003, **90**–**91**, 121–128.
44 I. Y. Park, D. Kim, J. Lee, S. H. Lee and K. J. Kim, *Mater. Chem. Phys.*, 2007, **106**, 149–157.
45 Happy, a I. Y. Tok, L. T. Su, F. Y. C. Boey and S. H. Ng, *J. Nanosci. Nanotechnol.*, 2007, **7**, 907–915.
46 X. Li, G. B. Ma and Y. Y. Liu, *Ind. Eng. Chem. Res.*, 2009, **48**, 763–768.
47 G. Li, C. Peng, C. Zhang, Z. Xu, M. Shang, D. Yang, X. Kang, W. Wang, C. Li, Z. Cheng and J. Lin, *Inorg. Chem.*, 2010, **49**, 10522–35.
48 R. K. Marella, K. S. Koppadi, Y. Jyothi, K. S. Rama Rao and D. R. Burri, *New J. Chem.*, 2013, **37**, 3229.
49 Y. Wei, S. Zhang, S. Yin, C. Zhao, S. Luo and C. T. Au, *Catal. Commun.*, 2011, **12**, 1333–1338.
50 a. S. Ivanova, B. L. Moroz, E. M. Moroz, Y. V. Larichev, E. a. Paukshtis and V. I. Bukhtiyarov, *J. Solid State Chem.*, 2005, **178**, 3265–3274.
51 a. Desmartin-Chomel, B. Hamad, J. Palomeque, N. Essayem, G. Bergeret and F. Figueras, *Catal. Today*, 2010, **152**, 110–114.
52 C.-G. Li, L. Xu, P. Wu, H. Wu and M. He, *Chem. Commun.*, 2014, **50**, 15764–15767.
53 G. Mascolo and M. C. Mascolo, *Microporous Mesoporous Mater.*, 2015, **214**, 246–248.

54 C. Li, M. Wei, D. G. Evans and X. Duan, *Catal. Today*, 2015, **247**, 163–169.
55 N. Kumar Verma, *Adv. Mater.*, 2015, **4**, 11.
56 B. Yu, J.-N. Xie, C.-L. Zhong, W. Li and L.-N. He, *ACS Catal.*, 2015, **5**, 3940–3944.
57 L. W. Diamond and N. N. Akinfiev, *Fluid Phase Equilib.*, 2003, **208**, 265–290.
58 O. Warr, C. a. Rochelle, A. Masters and C. J. Ballentine, *Geochim. Cosmochim. Acta*, 2015, **159**, 112–125.
59 M. T. Nguyen, M. H. Matus, V. E. Jackson, V. T. Ngan, J. R. Rostad and D. a. Dixon, *J. Phys. Chem. A*, 2008, **112**, 10386–10398.
60 M. Jödecke, Á. Pérez-Salado Kamps and G. Maurer, *J. Chem. Eng. Data*, 2012, **57**, 1249–1266.
61 B. Hirshberg and R. B. Gerber, *J. Phys. Chem. Lett.*, 2016, **7**, 2905–2909.
62 A. Stirling and I. Pápai, *J. Phys. Chem. B*, 2010, **114**, 16854–16859.
63 D. Pines, J. Ditkovich, T. Mukra, Y. Miller, P. M. Kiefer, S. Daschakraborty, J. T. Hynes and E. Pines, *J. Phys. Chem. B*, 2016, **120**, 2440–2451.
64 J. Ma, J. Hu, W. Lu, Z. Zhang and B. Han, *Phys. Chem. Chem. Phys.*, 2013, **15**, 17333–41.
65 M. S. Tiwari, G. D. Yadav and F. T. T. Ng, *Can. J. Chem. Eng.*, 2014, **92**, 2157–2165.
66 G. D. Yadav and R. K. Mewada, *Chem. Eng. J.*, 2013, **221**, 500–511.
67 Y. G. and G. P., *Clean Technol. Environ. Policy*, 2003, **4**, 227–234.
68 G. D. Yadav and N. S. Doshi, *Green Chem.*, 2002, **4**, 528–540.

La-Mg mixed oxide as highly basic water resistant catalyst for utilization of CO_2 in synthesis of quinazoline-2,4(1*H*,3*H*)-dione

Kalidas B. Rasal, Ganapati D. Yadav*

*Department of Chemical Engineering, Institute of Chemical Technology (ICT), Nathalal Parekh
Marg, Matunga (E), Mumbai - 400 019, INDIA.



Synthesis of Quinazoline-2,4(1*H*,3*H*)-dione using La-Mg mixed oxide in water