Heterocyclic Letters
Vol. 14| No.2|431-442|Feb-April|2024
ISSN : (print) 2231–3087 / (online) 2230-9632
CODEN: HLEEAI
http://heteroletters.org

"$CF_3SO_3H.SiO_2$ CATALYZED, SOLVENT FREE, 'N' AND 'O' FORMYLATION OF AMINES, ANILINES ALCOHOLS AND PHENOLS"

Shrikrishna G More[1], Mahesh P More[2], Parimeeta Chanchani [3]*

[1,3] Department of chemistry, Mansarovar Global University, Sehore, (M.P.), India.*
[2] Department of chemistry, Dr. A.P.J.Abdul Kalam University, Indore, (M.P.), India.
**Corresponding author: E-mail: parimeetac@gmail.com*

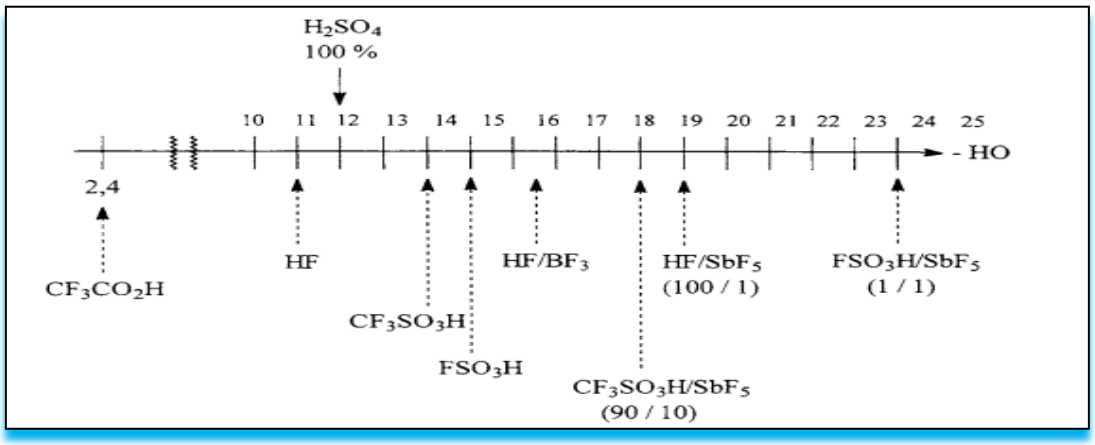
ABSTRACT
Ethyl Methanoate has been successfully employed as an 'N' and 'O' formylating agent in a straight forward way in presence of catalytic amount of $CF_3SO_3H.SiO_2$. This methodology is solvent free and economical for the synthesis of formamides and formats. The methodology shows wide range of tolerance of different aromatic and aliphatic amines, anilines and phenols offering well to excellent yield of the intended products within short reaction time. Late stage synthesis of formates and formamides also feasible using this methodology.

KEYWORDS: N-formylation; O-formylation; Formates; Formamides; solvent-free.

1. INTRODUCTION

One of the decisive fields of organic chemistry is the synthesis of formates and formamides, which are indispensable intermediates in the synthesis of several pharmacological substances such as cancer chemotherapy drugs, oxazolidinones, nitrogen-bridged heterocycles, fluoroquinolines, and other pharmaceutical substances. Both Formates and Formamides are engaged as polar solvents in a variety of chemical processes and are predominantly helpful reagents for Vilsmeier formylation [i-vii]. They are widely recognized for their ability to catalyse base catalysis processes, such as carbonyl compound hydrosilylation, allylation and peptide synthesis [viii-x]. In recent years, a number of techniques for formylation of amines and phenols have been devised [xi-xxiii]. Neat reaction in presence of formic acid [xxix-xxx], Amberlyst-15 [xxv], $NaHSO_4 \cdot H_2O$ [xxvi], Ammonium formate[xxvii], Acetic acid[xxviii], Chloral[xxix], Acetic formic anhydride[xxx], Melaminetrisulfonic acid[xxxi], Triethyl orthoformate[xxxii], Amberlite IR-120[xxxiii], Formic Acid-HI[xxxiv], Thiamine hydrochloride[xxxv], $HClO_4$-SiO_2[xxxvi], Sulfonic acid supported on hydroxyapatite (HAp)-encapsulated-γ-Fe_2O_3 nanocrystallites[xxxvii], Triflic anhydride[xxxviii], Calcium and hydrogen triflimides [$Ca(NTf_2)_2$, $HNTf_2$] [xxxix], Sulfuric Acid on Silica[xl], CF_3SO_3H[xli]. According to Hammet-Deyrup acidity scale, triflic acid shows more acidity as compaired with H_2SO_4, CF_3CO_2H and HF, represented in following figure-01.

Figure-01: *Hammet-Deyrup acidity scale*

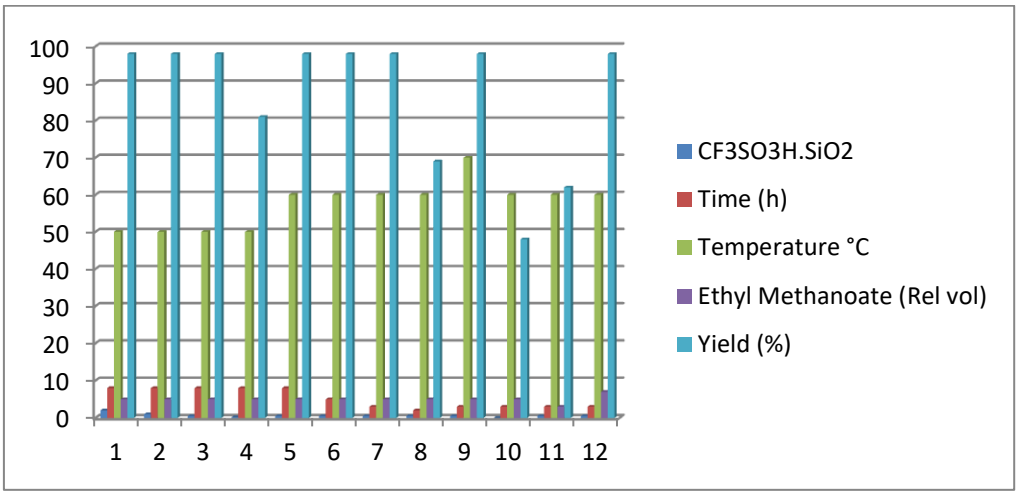


Unluckily, a lot of these techniques have disadvantages such using costly and hazardous formylating chemicals or costly catalysts, producing byproducts, or using an excessive quantity of formylating ratio of reagent to substrate, etc. Therefore, by considering all these facts herein we report $CF_3SO_3H.SiO_2$ as a catalyst for 'N' and 'O' formylation of amines, anilines, alcohols and phenols, which makes method more environmentally friendly and economically practical.

2. RESULTS AND DISCUSSION

Aniline and Ethyl Methanoate reaction was first selected as the model reaction. Equivalents of $CF_3SO_3H.SiO_2$ were optimized with respect to time and temperature. Ethyl Methanoate at (50-60) °C, yielding the intended product in a good to excellent yield in a short reaction time in presence of 50 mole% $CF_3SO_3H.SiO_2$ **(Figure-02, entry-7).** No impact of higher temperature observed with respect to time and yield while at lower temperature reaction takes more time for completion. Volumes of Ethyl Methanoate also optimized and it is observed that in 5.0 rel volumes is minimum requirement of reactions and it works smoothly, while at lower volumes reaction does not go to completion. However, during our investigation of $CF_3SO_3H.SiO_2$, we found that, in absence of catalyst, the reaction yielding an inferior amount of the desired products **(Figure-02, entry-10).** The established protocol's universality and effectiveness, we tested a variety of aromatic and heterocyclic Amines, anilines represented in **scheme-1 (summarized in Table-01)** and phenols as represented in **scheme-2 (summarized in Table-02)** respectively. The optimized reaction condition shows wide range of tolerance of multiple functional groups with consistent yields. Also triflic acid is readily available and cheaper chemical. It can be handled easily in the laboratory.

Figure-02: *Optimization of reaction conditions for the synthesis of 2-chloro-3-formyl quinolines and 2-chloro-3-acetyl quinolines and their reactions.*



* **Reaction conditions:** *1 (1.0eq.), $CF_3SO_3H.SiO_2$ (50 mole %) and Ethyl Formate (5.0 rel vol) was maintained at 60°C for 3.0 hour.*

Reaction Schemes:

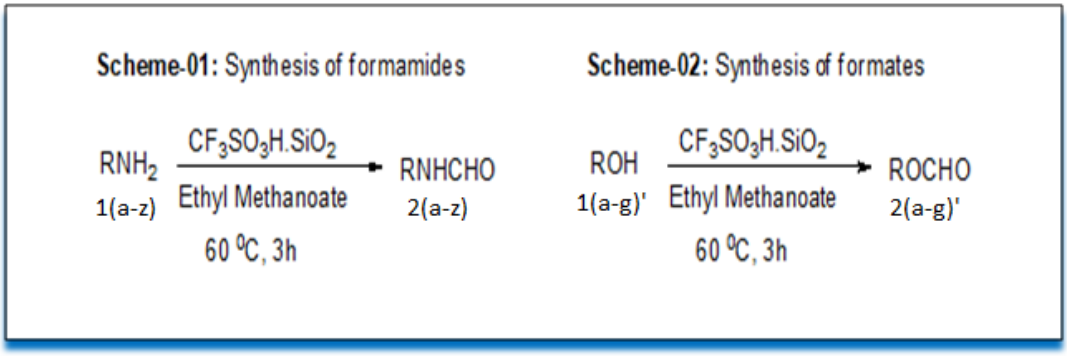
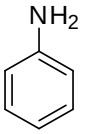
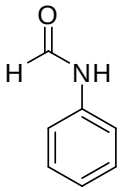
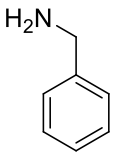
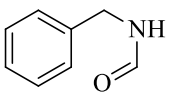
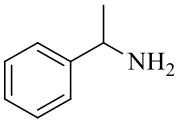
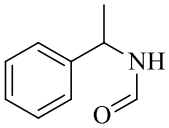
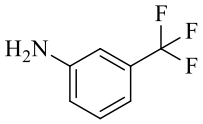
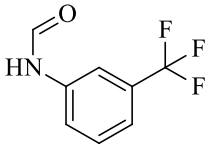
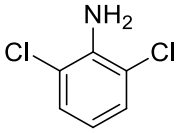
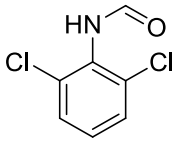
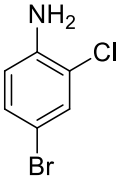
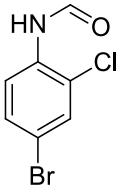
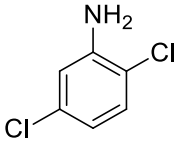
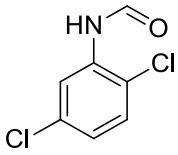
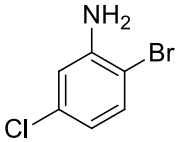
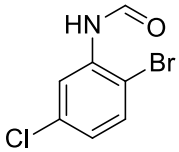
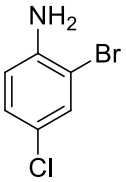
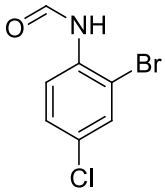
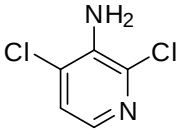
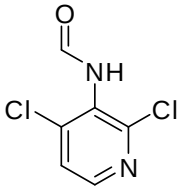
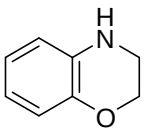
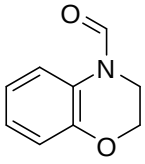
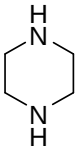
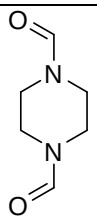
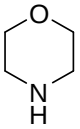
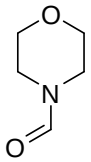
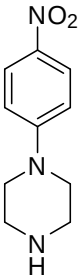
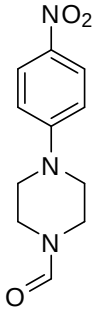
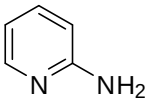
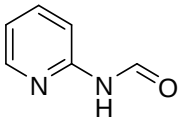
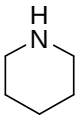
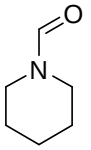
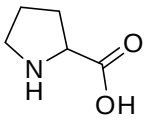
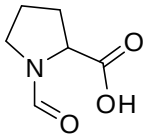
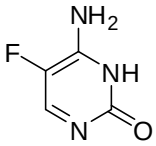
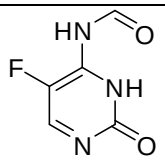
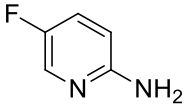
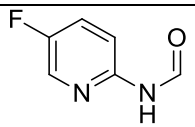
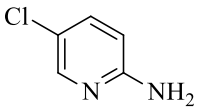
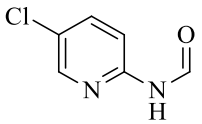
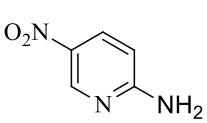
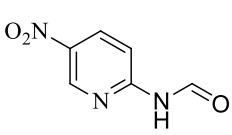
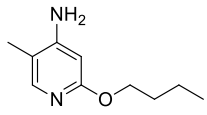
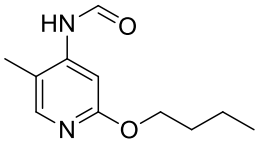
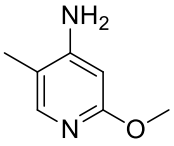
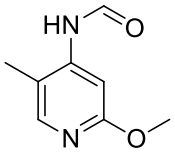
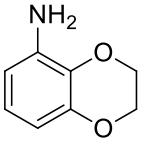
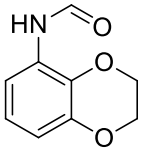
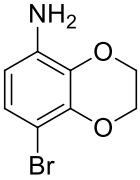
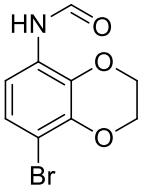
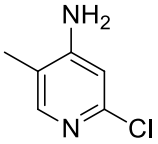
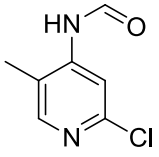


Table-01: *Exploration of reaction conditions on a selected Amines/Anilines i.e.1 (a-z) to afford products i.e.2 (a-z).*

Entry	(Ar)	Product	Yield (%)[Ref.%], Melting °C[Ref. °C], LC-MS, ^{1}H-NMR
1.		 (2a)	Yield-100 (100) [xliii], MP: 46-48(Reported: 46.6-47.5) [xlii], LC-MS: (ESI, m/z) $[M+H]^+$:122, ^{1}H-NMR, 400 MHz, $CDCl_3$: δ = 7.15-7.14 (1H,d), 7.33 (2H,dd), 7.54 (2H,dd), 8.4(1H, s)[lxxi]
2.		 (2b)	Yield-100 (99) [xliv], MP: 60-62(Reported: 59-60) [xlv], 1H-NMR, 400 MHz, CDCl3: δ = 4.30-4.32(2H, d), 7.23-7.45 (5H, m), 8.15(1H, s).
3.		 (2c)	Yield-100 (100) [xlvi], MP: 46-47(Reported: 48.5) [xlvii], 1H-NMR, 300 MHz, CDCl3: δ =1.34-1.47 (3H, d), 4.93- 5.08 (1H, q), 7.20-7.35 (5H, m), 8.53 (1H, s).

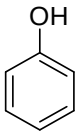
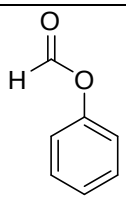
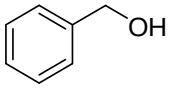
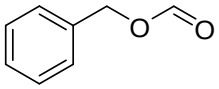
4.		 2d)	Yield-100 (100) [xlviii], 1H-NMR, 300 MHz, CDCl3: δ = 7.39-8.09 (4H, m), 8.36-8.37 (1H, s).[xlix]
5.		 (2e)	Yield-100 (99) [l], MP: 46-47(Reported: 175-178) [li], 1H-NMR, 300 MHz, CDCl3: δ= 6.53-6.60 (1H, dd), 7.23 (2H, d), 8.23 (1H, s).
6.		 (2f)	Yield-93, 1H-NMR, 300 MHz, DMSO: δ = 7.53-7.56 (1H, d), 7.78-7.79 (1H, d), 8.0-8.12(1H, s), 8.30 (1H, s).
7.		 (2g)	Yield-91, 1H-NMR, 300 MHz, DMSO: δ = 1H NMR: δ = 7.21 (1H, d), 7.53 (1H, d), 8.27 (1H, s), 8.37 (1H, s).
8.		 (2h)	Yield-89, 1H-NMR, 300 MHz, DMSO: δ = 1H NMR: δ =7.32 (1H, d), 7.68 (1H, d), 8.19 (1H, s), 8.38 (1H, s).
9.		 (2i)	Yield-94, 1H-NMR, 300 MHz, DMSO: δ = 1H-NMR: δ = 5.61 (1H, d), 6.77-6.80 (1H, d), 7.08-7.11 (1H, s), 7.39-7.40 (1H, s).
10.		 (2j)	Yield-55 (43) [lii], 1H-NMR, 300 MHz, CDCl3: δ=7.22(1H, d), 7.93(1H, d), 8.34(1H, s).
11.		 (2k)	Yield-95 (93) [lvii], LC-MS: (ESI, m/z) $[M+H]^+$:164, 1H-NMR, 400 MHz, CDCl3: δ = 3.93 (t,2H),4.24 (t, 2H), 6.96 - 6.91 (m, 2H), 7.08 (t, 1H),7.20 (d, 1H),8.84 (s, 1H)[lviii]
12.		 (2l)	Yield-99 (99) [lix], MP: 128-130(Reported: 126-127) [lx], 1H-NMR, 400 MHz, CDCl3: δ =3.21-3.39(8H, m), 8.04-8.12(2H, s)[lviii].

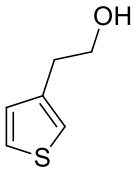
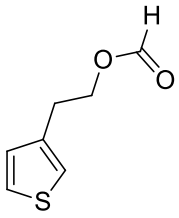
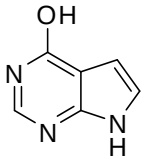
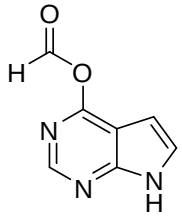
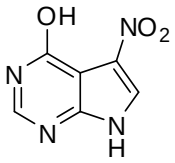
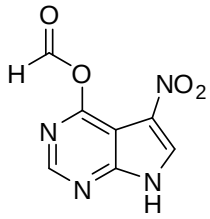
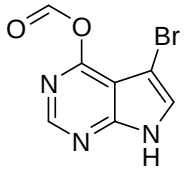
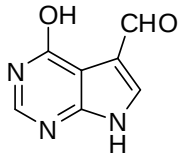
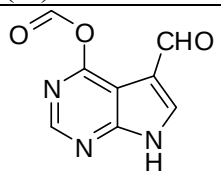
13.		 (2m)	Yield-100(100) [lix], MP: 21-23 (Reported: 20-21) [lxi] LC-MS: (ESI, m/z) $[M+H]^+$:88, 1H-NMR, 300 MHz, DMSO: δ=3.20-3.22(8H, m), 8.14(1H,s)[lviii].
14.		 (2n)	Yield-98(95) [lvii], MP: 125-127 (Reported: 126-128) [lxiv], 1H-NMR, 400 MHz, CDCl3: δ = 3.12-3.31(8H, m), 6.71(2H, d), 6.88(2H, d), 8.14(1H, s).
15.		 (2o)	Yield-98(93) [lxv], MP: 68-70 (Reported: 69-70) [lxvi], 1H-NMR, 400 MHz, CDCl3: δ = 6.81-6.95(1H, t), 4.95(1H, t), 8.09(2H, d), 8.52(1H, s).
16.		 (2p)	Yield-95(91) [lxvii], 1H-NMR, 300 MHz, CDCl3: δ = 1.49-1.62(4H, q), 1.65-1.69(2H, q), 3.25-3.35(2H, t), 3.45-3.55(2H, t), 7.95-8.15(1H, s)[lxxii]
17.		 (2q)	Yield-96(93) [lxx], 1H-NMR, 300 MHz, CDCl3: δ = 8.81(s, 1H), 8.26 -8.29(s, 1H), 4.51–4.41(t, 1H), 3.67–3.51(q, 2H), 2.29–2.20(q, 2H), 2.08–1.87 (q, 2H)[lxx].
18.		 (2r)	Yield-83, 1H-NMR, 300 MHz, DMSO: δ = 1H-NMR, 400 MHz, δ= 7.83 (1H, d)[74], 8.38 (1H, s).[lxxiv]
19.		 (2s)	Yield-93, 1H-NMR, 300 MHz, DMSO: δ = 6.98 (1H, dd), 7.70 (1H, d), 8.25 (1H, d), 8.32 (1H, s).
20.		 (2t)	Yield-85, LC-MS: (ESI, m/z) $[M+H]^+$:156.01,158.03, 1H-NMR, 300 MHz, DMSO: δ = 6.00-6.14 (1H, d), 6.44-6.47 (1H, d), 7.39-7.43 (1H, s), 7.88 (1H, s).
21.		 (2u)	Yield-84, LC-MS: (ESI, m/z) $[M+H]^+$:167.12 [lxxiii], 1H-NMR, 300 MHz, DMSO: δ = 6.49-6.52(1H, d), 7.55 (1H, d), 8.11-8.15 (1H, s), 8.85 (1H, s)

22.		 (2v)	Yield-93, 1H-NMR, 300 MHz, DMSO: δ = 0.86-0.91 (3H,t), 1.39-1.32(2H, qui.), 1.55-1.62 (2H, qui), 1.91 (3H, s), 4.05-4.09 (2H, t), 5.84-5.85 5.84 (1H, s), 5.85 (1H, s), 7.48 (1H, s), 8.14 (1H, s).
23.		 (2w)	Yield-79, 1H-NMR, 300 MHz, DMSO: δ = 1H NMR: δ = 1.91 (3H, s), 3.67 (3H, s), 6.70 (1H, s), 6.85 (1H, s), 7.49 (1H, s), 8.15 (1H, s).
24.		 (2x)	Yield-95, 1H-NMR, 300 MHz, DMSO: δ = 4.17-4.32(4H, t),6.59(1H,dd),6.73-6.78(1H,d),7.68-7.71(1H,d),8.27-8.28(1H,s)
25.		 (2y)	Yield-81, 1H-NMR, 300 MHz, DMSO: δ= 4.32-4.36 (4H, t], 6.75 (1H, d), 7.06 (1H, d), 8.29 (1H, s).
26.		 (2z)	Yield-79, 1H-NMR, 300 MHz, DMSO: δ = 1.97 (3H, s), 6.17 (1H, s), 6.50(1H, s), 7.69 (1H, s)

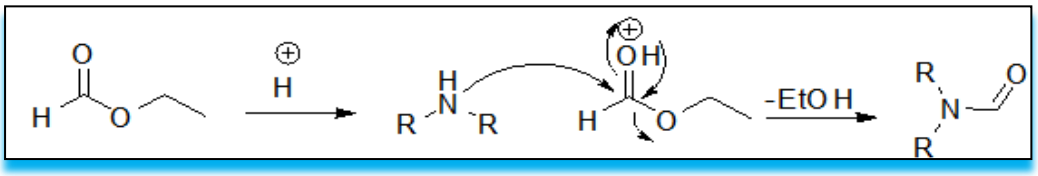
** [Ref.]: References*

Table-02: *Exploration of reaction conditions on a selected phenols 1 (a-g)' to afford products2 (a-g)'.*

Entry	(Ar)	Product	Yield (%)[Ref.%], Melting °C(%)[Ref. °C], LC-MS, ^{1}H-NMR
1.		 (2a)'	Yield-90 (85) [liii], MP: 36-38(Reported: 33-37) [liv], LC-MS: (ESI, m/z) $[M+H]^+$:123, ^{1}H-NMR, 400 MHz, DMSO: δ = 7.12-7.20(3H,m), 7.25(2H,m), 8.26(1H,s)
2.		 (2b)'	Yield-100 (99) [lv], MP: 60-62(Reported: 8.2-8.4) [lvi], LC-MS: (ESI, m/z) $[M+H]^+$:137, 1H-NMR, 300 MHz, DMSO: δ = 7.31-7.36(5H,m),4.98(2H,s),9.62(1H,s)

3.		 (2c)'	Yield-99, 1H-NMR, 300 MHz, DMSO: δ = 2.91-2.96(2H,t),4.29-4.33(2H,t),7.01-7.02(1H,d),7.26-7.27(1H,d),7.47-7.48(1H,d),8.20(1H,s).
4.		 (2d)'	Yield-68, 1H-NMR, 300 MHz, DMSO: δ = 6.43-6.45(1H,d), 7.03-7.05(1H,d),7.83(1H,s), 9.65(1H,s)
5.		 (2e)'	Yield-51, 1H-NMR, 300 MHz, DMSO: δ = 7.50(1H,s),8.14(1H,s),12.33(1H,s)9.66(1H,s)
6.		 (2f)'	Yield-61, 1H-NMR, 300 MHz, DMSO: δ = 8.17 (1H, s), 8.75 (1H, s), 9.66 (1H, s), 10.08 (1H, s).
7.		 (2g)'	Yield-49, 1H-NMR, 300 MHz, CDCl3: δ = 8.13 (1H, s), 8.67 (1H, s), 9.66 (1H, s), 10.02 (1H, s).

3.Proposed Mechanism: Plausible mechanism represented as follows,



4.Experimental Section:

The purest available chemicals were purchased from S.D. Fine Chemicals Ltd. and Sigma-Aldrich. The substances were utilized without any kind of purifications. Using analytical techniques such as LC-MS, 1H-NMR and physical parameter such as melting points were used for the characterization of synthesized molecules. Progress of the reaction monitored by TLC (Coated on silica gel)

4.1 Preparation of silica supported Trifluoromethanesulfonic Acid.

The silica supported trifluoromethanesulfonic acid was prepared by mixing Silica gel (45.0 g, Merck grade 60, 100–200 mesh) with a trifluoromethanesulfonic acid (5.0 g) in distilled water (30mL). The resulting mixture was stirred for 60 min to for absorption of Magnesium trifluoromethanesulfonic acid on the surface of silica gel. After complete absorption, Water removed by vacuum distillation on rotary evaporator.

The isolated solid powder was dried at 120°C for 5 h under reduced vacuum.

4.2 General procedure for the preparation of Formamides [2(a-r)].

Typically, an experimental approach involved the cautious addition of aniline (1.0 mmol), Ethyl Methanoate (5.0 rel volume) and 50.0 mole % $CF_3SO_3H.SiO_2$ 3.0h at 60°C. TLC kept an eye on the reaction's development. Following the completion of the reaction, ethyl formate removed by vacuum under negative pressure. Pure N-formylated products were obtained by isolating the residue using MTBE re-crystallization at lower temperature. Every product was well-known and confirmed with genuine reported samples and was assessed using Melting points, LC-MS and 1*H*-NMR.

Similar protocol used for the synthesis of remaining Amines and anilines summarized in **Table-1.**

4.3 General procedure for the preparation of Formates [2(a-r)].

Typically, an experimental approach involved the cautious addition of phenol (1.0 mmol), Ethyl Methanoate (5.0 rel volume) and 50.0 mole % $CF_3SO_3H.SiO_2$ 3.0h at 60°C. TLC kept an eye on the reaction's development. Following the completion of the reaction, Ethyl formate removed by vacuum under negative pressure. Pure N-formylated products were obtained by isolating the residue using MTBE re-crystallization at lower temperature. Every product was well-known and confirmed with genuine reported samples and was assessed using Melting points, LC-MS and 1*H*-NMR.

Similar protocol used for the synthesis of remaining Amines and anilines summarized in **Table-2.**

5.CONCLUSION

In the summary, we have developed a relatively straightforward, solvent free and effective process for the synthesis of several formates and formamides using $CF_3SO_3H.SiO_2$ catalyst. This method's noteworthy benefits include short reaction time, easy operation, a high product yield, and cost effectiveness. The developed methodology is commercially viable and shows wide range of tolerance of maximum functional group. This methodology can be utilized in late stage development of drug molecules due to its mildness.

6.ACKNOWLEDGMENT

Authors sincerely thank to Department of chemistry, Mansarovar Global University, Sehore, (M.P.), India, for their support.

7. REFERENCES:

i. Jackson, A.; Meth-Cohn, O. J. Chem. Soc., Chem. Commun. 1995, 13191320.
ii. Kakehi, A.; Ito, S.; Hayashi, S.; Fujii, T. Bull. Chem. Soc. Jpn. 1995, **68**, 35733580.
iii. Lohray, B.B.; Baskaran, S.; Rao, B.S.; Reddy, B.Y.; Rao, I.N. Tetrahedron Lett. 1999, **40**, 48554856.
iv. Petit, G.R.; Kalnins, M.V.; Liu, T.M.H.; Thomas, E.G.; Parent, K. J. Org. Chem. 1961, **26**, 25632566.
v. Kobayashi, K.; Nagato, S.; Kawakita, M.; Morikawa, O.; Konishi, H. Chem. Lett. 1995, 24, 575576. R N OR1 O H H H OR1 H O R-NH2 R N H H O R NH OH H OR1

+ - R1OH Heat Figure 1. Proposed mechanism for N-formylation of amines using formic acid/ethyl formate. Green Chemistry Letters and Reviews 155 Downloaded by [117.218.173.74] at 21:50 20 April 2015

vi. Chen, B.C.; Bendarz, M.S.; Zhao, R.; Sundeen, J.E.; Chen, P.; Shen, Z.; Skoumbourdis, A.P.; Barrish, J.C. Tetrahedron Lett. 2000, **41**, 54535456.

vii. Downie, I.M.; Earle, M. J.; Heaney, H.; Shuhaibar, K.F. Tetrahedron 1993, **49**, 40154034.

viii. Kobayashi, S.; Nishio, K. J. Org. Chem. 1994, **59**, 66206628.

ix. Kobayashi, S.; Yasuda, M.; Hachiya, I. Chem. Lett. 1996, **25**, 407408.

x. Martrniez, J.; Laur, J. Synthesis 1982, 979980.

xi. Blicke, F.F.; Lu, C.J. J. Am. Chem. Soc. 1952, **74**, 39333934.

xii. Waki, J.; Meinhofer, J. J. Org. Chem. 1977, **42**, 2019 2026.

xiii. Chen, F.M.F.; Benoiton, N.L. Synthesis. 1979, 709 710.

xiv. Yale, H.L. J. Org. Chem. 1971, **36**, 32383240.

xv. Kisfaludy, L.; Laszlo, O. Synthesis 1987, 510.

xvi. Duezek, W.; Deutsch, J.; Vieth, S.; Niclas, H.J. Synthesis 1996, 3738.

xvii. Mihara, M.; Ishino, Y.; Minakara, S.; Komatsu, M. Synthesis 2003, 23172320.

xviii. Das, B.; Krishnaiah, M.; Balasubramanayam, P.; Veeranjaneyulu, B.; Kumar, D.N. Tetrahedron Lett. 2008, **49**, 22252227.

xix. Reddy, P.G.; Kumar, G.D.K.; Bhaskaran, S. Tetrahedron 2000, **41**, 91499151.

xx. Luca, L.D.; Giacomelli, G.; Porcheddu, A.; Salaris, M. Synlett 2004, 25702572.

xxi. Deutsch, J.; Eckelt, R.; Ko¨ckritz, A.; Martin, A. Tetrahedron 2009, **65**, 1036510369.

xxii. Chandra Shekhar, A.; Ravi Kumar, A.; Sathaiah, G.; Luke Paul, V.; Sridhar, M.; Shanthan Rao, P. Tetrahedron Lett. 2009, **50**, 70997101.

xxiii. Hosseini-Sarvari, M.; Sharghi, H. J.Org. Chem. 2006, **71**, 66526654.

xxiv. Brahmachari, G.; Laskar, S. Tetrahedron Lett. 2010, **51**, 23192322

xxv. Singh A S., Bhanage B M., Nagarkar J M., Green Chemistry Letters and Reviews, Vol. **5**, No. 1, March 2012, 2732.

xxvi. Behzad Zeynizadeh* and Mohammad Abdollahi, Current Chemistry Letters 5 (2016) 51–58.

xxvii. P. Ganapati Reddy, G. D. Kishore Kumar and S. Baskaran*, Tetrahedron Letters 41 (2000) 9149–9151.

xviii. Iraj Mohammadpoor-Baltork,* Ahmad Reza Khosropour and Hamid Aliyan, J. CHEM. RESEARCH (S), 2001.

xxix. Blicke, F.F.; Lu, C.-J. Formylation of amines with chloral and reduction of the N-formyl derivatives with lithium aluminum hydride. J. Am. Chem. Soc. 1952, **74**, 3933–3934.

xxx. Jung, S.H.; Ahn, J.H.; Park, S.K.; Choi, J.-K. A practical and convenient procedure for the N-formylation of amines using formic acid. Bull. Korean Chem. Soc. 2002, **23**, 149–150.

xxxi. Yang, X.; Zhang, Y. Melamine trisulfonic acid-catalyzed N-formylation of amines under solvent-free conditions. Res. Chem. Intermed. 2012, 1–6.

xxxii. Swaringen, R.A.; Eaddy, J.F.; Henderson, T.R. Reaction of ortho esters with secondary amines. J. Org. Chem. 1980, **45**, 3986–3989

xxiii. Muthukur Bhojegowd, M.R.; Nizam, A.; Pasha, M.A. Amberlite IR-120: A reusable catalyst for N-formylation of amines with formic acid using microwaves. Chin. J. Catal. 2010, **31**, 518–520.

xxiv. Hammick, D.L.; Zvegintzov, M. CXLIV.-The rate of reaction between formic acid and iodine in aqueous solution. J. Chem. Soc. 1926, **129**, 1105–1108.

xxv. Lei, M.; Ma, L.; Hu, L. A convenient one-pot synthesis of formamide derivatives using thiamine hydrochloride as a novel catalyst. Tetrahedron Lett. 2010, **51**, 4186–4188.

xxvi. Ansari, M.I.; Hussain, M.K.; Yadav, N.; Gupta, P.K.; Hajela, K. Silica supported perchloric acid catalyzed rapid N-formylation under solvent-free conditions. Tetrahedron Lett. 2012, **53**, 2063–2065.

xxvii. Ma'mani, L.; Sheykhan, M.; Heydari, A.; Faraji, M.; Yamini, Y. Sulfonic acid supported on hydroxyapatite-encapsulated-γ-Fe2O3 nanocrystallites as a magnetically Brønsted acid for N-formylation of amines. Appl. Catal. A 2010, **377**, 64–69.

xviii. Swetha Bharamawadeyar & Vommina V Sureshbabu* , Synthesis of N-aryl derived formamides using triflic anhydride , Indian Journal of Chemistry Vol. 62, June 2023, pp. 656-661

xxix. Eric Tan,[a] Sosthène Ung,[a] and Matthieu Corbet*, Microwave-Assisted Formylations of Weakly Basic Anilines with Methyl Formate Catalyzed by Calcium and Hydrogen Triflimides, Eur. J. Org. Chem. 2016, 1836–1840.

xl. Sodeeq Aderotimi Salami 1,* , Xavier Siwe-Noundou 2,* and Rui W. M. Krause 1, Catalytic Performance of Immobilized Sulfuric Acid on Silica Gel for N-Formylation of Amines with Triethyl Orthoformate, Molecules 2022, **27**, 4213.

xli. Brian L. Booth." Teymour A. El-Fekky. and Ghazi F. M. Noori, Formylation and Acylation Reactions Catalysed by Trifluoromethanesulphonic Acid, J. Chem. Soc., Perkin Trans. 1, 1980, 181-186.

xlii. Sonawane, Rahul B.; ChemCatChem, (2018), **10**(17), 3907-3913, CAplus

xliii. Abdollahi, Mohammad; Zeynizadeh, Behzad; Sadighnia, Leila, New catalytic performance of immobilized sulfuric acid on activated charcoal for N-formylation of amines with ethyl formate, Journal of the Chemical Society of Pakistan (2017), **39**(4), 619-627.

xliv. Patre, Rupesh E.; Mal, Sanjib; Nilkanth, Pankaj R.; Ghorai, Sujit K.; Deshpande, Sudhindra H., First report on bio-catalytic N-formylation of amines using ethyl formate, Chemical Communications (Cambridge, United Kingdom) (2017), **53**(15), 2382-2385.

xlv. Kisfaludy, Lajos; Synthesis, (1987)(5), **510**, CAplus

xlvi. Funk, Pierre; Richrath, Ruben B.; Bohle, Fabian ; Grimme, Stefan ; Gansaeuer, Andreas, Oxidation Under Reductive Conditions: From Benzylic Ethers to Acetals with Perfect Atom-Economy by Titanocene(III) Catalysis, Angewandte Chemie, International Edition (2021), **60**(10), 5482-5488.

xlvii. Bezruchko, V. T.; Zhurnal Obshchei Khimii, (1967), **37**(7), 1467-73, CAplus

xlviii. Russo, Camilla; Donati, Greta; Giustiniano, Francesco; Amato, Jussara; Marinelli, Luciana, Isocyanides as Catalytic Electron Acceptors in the Visible Light Promoted Oxidative Formation of Benzyl and Acyl Radicals, Chemistry - A European Journal (2023), **29**(60), e202301852.

xlix. Tan, Eric; European Journal of Organic Chemistry, (2016), 2016(10), 1836-1840, CAplus,

l. Nawwar-Masari, Galal A., A convenient facile process synthesis of 2,6-dichloro-diphenylamine the key intermediate for the synthesis of 2-(2,6-dichloroanilino)phenylacetic acid (diclofenac, voltaren) utilizing the firstly reported N-formyl-2,6-dichlorodiphenylamine, Egypt, EG21151 A 2000-12-31.

li. Toldy, Lajos; HU155329, 1968, CAplus

lii. Cabral, Shawn; Canterbury, Daniel Paul; Dow, Robert Lee; Fensome, Andrew; Korczynska, Magdalena, Preparation of (aza)benzothiazolyl substituted pyrazole

compounds for treating transthyretin amyloidosis and diseases, World Intellectual Property Organization, WO2022112919 A1 2022-06-02.

liii. Taheri, Sepideh; Veisi, Hojat; Hekmati, Malak, Application of polydopamine sulfamic acid-functionalized magnetic Fe3O4 nanoparticles (Fe3O4@PDA-SO3H) as a heterogeneous and recyclable nanocatalyst for the formylation of alcohols and amines under solvent-free conditions, New Journal of Chemistry (2017), **41**(12), 5075-5081 .

liv. Hine, Jack; Journal of the American Chemical Society, (1950), **72**, 2438-45, CAplus

lv. Ghorbani-Vaghei, R.; Veisi, H.; Amiri, M., Poly(N,N'-dichloro-N-ethyl-benzene-1,3-disulfonamide), N,N,N',N'-tetrachlorobenzene-1,3-disulfonamide, poly(N,N'-dibromo-N-ethyl-benzene-1,3-disulfonamide), and N,N,N',N'-tetrabromobenzene-1,3-disulfonamide catalyzed formylation of amines and alcohols using ethyl formate under microwave irradiation, Journal of the Iranian Chemical Society (2009), **6**(4), 761-768.

lvi. Cardellini, Fabio; Synthetic Communications, (2014), **44**(22), 3248-3256, CAplus

lvii. Ganapati Reddy, P.; Kishore Kumar, G. D.; Baskaran, S., A convenient method for the N-formylation of secondary amines and anilines using ammonium formate, Tetrahedron Letters (2000), **41**(47), 9149-9151.

lviii. Li, X.-F., Zhang, X.-G., Chen, F., & Zhang, X.-H. (2018). Copper-Catalyzed N-Formylation of Amines through Tandem Amination/Hydrolysis/Decarboxylation Reaction of Ethyl Bromodifluoroacetate. The Journal of Organic Chemistry. doi:10.1021/acs.joc.8b01555

lix. Liu, Jian-Wei; Wang, Ying; Kang, Li-Xia; Zhao, Yan; Xing, Guang-Yan; Huang, Zheng-Yang; Zhu, Ya-Cheng; Li, Deng-Yuan ; Liu, Pei-Nian Journal of the American Chemical Society (2023), **145**(24), 13048-13058

lx. Ghorbani-Vaghei, R.; Veisi, H.; Amiri, M., Poly(N,N'-dichloro-N-ethyl-benzene-1,3-disulfonamide), N,N,N',N'-tetrachlorobenzene-1,3-disulfonamide, poly(N,N'-dibromo-N-ethyl-benzene-1,3-disulfonamide), and N,N,N',N'-tetrabromobenzene-1,3-disulfonamide catalyzed formylation of amines and alcohols using ethyl formate under microwave irradiation, Journal of the Iranian Chemical Society (2009), **6**(4), 761-768 .

lxi. Mislyuk, O. A.; Khimiya Geterotsiklicheskikh Soedinenii, (1985)(6), 851-2, CAplus

lxii. Smith, G. B. L.; Journal of the American Chemical Society, (1948), **70**, 4254, CAplus

lxiii. Nishikawa, Yasuhiro; Tetrahedron Letters, (2017), **58**(9), 860-863, CAplus

lxiv. Takahashi, Toshiyuki; Bioorganic & Medicinal Chemistry, (2006), **14**(22), 7501-7511, CAplus

lxv. Pathare, Sagar P.; Jain, Ashish Kumar H.; Akamanchi, Krishnacharya G., Sulfated tungstate: a highly efficient catalyst for transamidation of carboxamides with amines, RSC Advances (2013), **3**(21), 7697-7703.

lxvi. Chiang, Kun-Heng; Heteroatom Chemistry, (2016), **27**(4), 235-242, CAplus

lxvii. Takaishi, Kazuto; Nath, Bikash Dev; Yamada, Yuya; Kosugi, Hiroyasu; Ema, Tadashi , Unexpected Macrocyclic Multinuclear Zinc and Nickel Complexes that Function as Multitasking Catalysts for CO2 Fixations, Angewandte Chemie, International Edition (2019), **58**(29), 9984-9988.

lxviii. Li, Xue-Dong; Green Chemistry, (2018), **20**(21), 4853-4858, CAplus,

lxix. Jagtap, Sunil B.; Tsogoeva, Svetlana B., First enantioselective organocatalytic allylation of simple aldimines with allyltrichlorosilane, Chemical Communications (Cambridge, United Kingdom) (2006), (**45**), 4747-4749.

lxx. Baudequin, Christine; European Journal of Organic Chemistry, (2007)(**16**), 2623-2629, CAplus

lxxi. Abraham, R. J., Griffiths, L., & Perez, M. (2013). 1H NMR spectra. Part 30:1H chemical shifts in amides and the magnetic anisotropy, electric field and steric effects

of the amide group. Magnetic Resonance in Chemistry, **51**(3), 143–155. doi:10.1002/mrc.3920

lxxii. Liu, Z., Yang, Z., Ke. Z., Yu. X., Zhang, H., Yu, B, Liu, Z. (2018). Ethanol-mediated N-formylation of amines with CO2/H2 over cobalt catalysts. New Journal of Chemistry, **42**(16), 13933–13937. doi:10.1039/c8nj03047b

xxiii. Mironov, M. A.; Mokrushin, V. S. ,Synthesis and reactions of aromatic and heterocyclic isocyanides, Russian Journal of Organic Chemistry (Translation of Zhurnal Organicheskoi Khimii) (1999), **35**(5), 693-697

xxiv. Antal Harsanyi, Annelyse Conte, Laurent Pichon, Alain Rabion, Sandrine Grenier, and Graham Sandford, One-Step Continuous Flow Synthesis of Antifungal WHO Essential Medicine Flucytosine Using Fluorine, Organic Process Research & Development, February 17, 2017(141-276)

Received on January 14, 2023.