Life cycle assessment of multistep benzoxazoles synthesis: from batch to waste-minimized continuous flow systems

Jose Osorio-Tejada,[a] Francesco Ferlin,[b] Luigi Vaccaro,[b] Volker Hessel,[a,c]

[a] Department of Chemical Engineering, School of Engineering, University of Warwick, Coventry, UK
[b] Laboratory of Green S.O.C. – Dipartimento di Chimica, biologia e Biotecnologie, Università degli Studi di Perugia, Via Elce di Sotto 8, 06123 – Perugia, Italy. E-mail: luigi.vaccaro@unipg.it; http://greensoc.chm.unipg.it/ .
[c] School of Chemical Engineering and Advanced Materials, University of Adelaide, Adelaide, Australia

Electronic Supplementary Information (ESI1)

LCA INVENTORIES DATASET

Inventories for the nine benchmarked synthesis processes

Table 1. CF approach OMS multigram scale

Inputs	Quantity for 53.5 g of product[1]	Quantity for 1 g of product	Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
Benzyl alcohol	33.3 g	6.22E-01 g	1.24E-03	7.66E-02	6.52E-03	6.97E-03
CPME (cyclopentyl methyl ether)	610 g	2.28E-01 g	2.28E-02	3.43E-01	1.99E-02	5.36E-02
o-aminophenol	30.5 g	5.70E-01 g	0	1.73E-02	1.09E-03	2.94E-03
K-OMS	68 mg	2.54E-08 g	0	0	1.27E-08	1.27E-08
H-OMS	78 mg	2.92E-08 g	0	0	1.46E-08	1.46E-08
O2 (3.88 L of gas)	5.5 g	1.04E-01 g	0	0	0	0.00E+00
N2 (3.02 L of gas)	3.8 g	7.06E-02 g	0	0	0	0.00E+00
Ethanol	71 g	3.85E-01 g	2.65E-03	4.63E-01	3.71E-02	9.98E-02
Heating at 106 °C for 24 h		2.43E-02 kWh				
Energy to recover solvents		3.03E-03 kWh				
Chemical factory		4.00E-13 unit				

Table 2. CF approach OMS small scale

Inputs	Quantity for 0.708 g of product[1]	Quantity for 1 g of product	Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
Benzyl alcohol	0.432 g	6.10E-01 g	1.22E-03	9.95E-02	5.34E-03	1.44E-02
CPME	24 g	6.78E-01 g	6.78E-02	1.02E+00	5.92E-02	1.59E-01
o-aminophenol	0.404 g	5.71E-01 g		1.81E-02	1.14E-03	3.07E-03
K-OMS	68 mg	1.92E-06 g		0	9.60E-07	9.60E-07
H-OMS	78 mg	2.20E-06 g		0	1.10E-06	1.10E-06
O2 (3.88 L of gas)	0.08 g	1.12E-01 g				
N2 (3.02 L of gas)	0.05 g	7.62E-02 g				
Ethanol	3.90 g	1.60E+00 g	1.10E-02	1.92E+00	1.54E-01	4.14E-01
Heating at 106 °C for 58 min		6.28E-03 kWh				
Energy to recover solvents		9.77E-03 kWh				
Chemical factory		4.00E-13 unit				

Table 3. Batch approach OMS

Inputs	Quantity for 0.037 g of product[1]	Quantity for 1 g of product	Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
Benzyl alcohol	0.043 g	1.16E+00 g	2.32E-03	1.10E+00	5.88E-02	1.58E-01
CPME	5.16 g	2.79E+00 g	2.79E-01	4.20E+00	2.43E-01	6.56E-01
o-aminophenol	0.022 g	5.95E-01 g		5.49E-02	3.47E-03	9.34E-03
K-OMS	17.7 g	9.57E-06 g			4.78E-06	4.78E-06
H-OMS	35.4 g	1.91E-05 g			9.57E-06	9.57E-06
O2						
N2						
Ethanol	3.90 g	1.24E+01 g	8.54E-02	1.49E+01	1.19E+00	3.21E+00
Heat (106 °C for 70 min)		6.05E-02 kWh				
Energy to recover solvents		5.00E-02 kWh				
Chemical factory		4.00E-13 unit				
Energy to regenerate catalysts		7.74E-02 kWh				

Table 4. Batch approach via dichlorodicyanobenzoquinone (DDQ) - Chang et al. 2002

Inputs	Quantity for 0.181 g of product[2]	Quantity for 1 g of product	Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
o-aminophenol	0.109 g	6.02E-01 g		6.66E-02	4.21E-03	1.13E-02
Methanol	3.9 g	6.25E+00 g	4.31E-02	5.42E+00	6.02E-01	1.62E+00
Benzaldehyde	0.106 g	5.86E-01 g	1.17E-03	7.55E-02	3.97E-03	1.07E-02
Dichloromethane	26.6 g	4.26E+01 g	2.94E-01	13.9E+00	4.11E+00	1.11E+01
DDQ	0.25 g	1.38E+00 g			1.38E+00	
Saturated Sodium carbonate	22 g	1.22E+02 g			1.22E+02	
Brine	11.5 g	6.35E+01 g			6.35E+01	
Ethyl acetate in chrom. column	0.016 g	9.02E-02 g	1.80E-04	1.14E-01	8.73E-03	2.35E-02
Hexane in chrom. column	0.1067 g	5.90E-01 g	1.18E-03	1.14E+00	5.71E-02	1.54E-01
Heat (45 °C 12 h) and stir (30 min)		3.24E-02 kWh				
Energy to recover solvents		4.25E-02 kWh				
Chemical factory		4.00E-13 unit				

Table 5. Batch approach via phosphonium acidic ionic liquid - Nguyen et al. 2018

Inputs	Quantity for 0.177 g of product[3]	Quantity for 1 g of product	Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
o-aminophenol	0.109 g	6.16E-01 g		8.75E-02	5.53E-03	1.49E-02
Benzaldehyde	0.106 g	5.99E-01 g	1.20E-03	9.99E-02	5.26E-03	1.42E-02
Phosphonium acidic ionic liquid	0.0205 g	2.90E-02 g		4.26E-02	2.81E-03	7.56E-03
Diethyl ether (10 x 5 mL)	35.6 g	5.83E+01 g	4.02E-01	8.73E+01	5.62E+00	1.51E+01
Acetone in chrom. column	0.007 g	3.92E-02 g	7.84E-05	5.64E-02	3.79E-03	1.02E-02
Petroleum Ether in chrom. column	0.108 g	6.08E-01 g	1.22E-03	1.18E+00	5.89E-02	1.59E-01
Heat and stir (100 °C 30 min)		8.78E-04 kWh				
Energy to recover Phosphonium		3.78E-02 kWh				
Energy to recover solvents		3.78E-02 kWh				
Chemical factory		4.00E-13 unit				

Table 6. Batch approach via Ru-catalysed ADC reactions - Khalafi & Panahi 2014

Inputs	Quantity for 0.152 g of product[4]	Quantity for 1 g of product	Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
o-aminophenol	0.109 g	7.17E-01 g		2.43E-01	1.54E-02	4.13E-02
Benzyl alcohol	0.112 g	7.37E-01 g	1.47E-03	3.28E-01	1.76E-02	4.74E-02
Toluene	2.6 g	4.96E+00 g	3.42E-02	1.05E+01	4.78E-01	1.29E+00
DABCO	0.06 g	3.95E-01 g	7.89E-04	5.89E-01	3.82E-02	1.03E-01
PFMN ligand	0.05 g					
Ru2Cl4(CO)6	0.01 g	1.10E-02 g			1.10E-02	
Diethyl ether	21.4 g	4.08E+01 g	2.82E-01	6.11E+01	3.93E+00	1.06E+01
Ethyl acetate in chrom. column	0.069 g	4.51E-01 g	9.02E-04	5.71E-01	4.37E-02	1.18E-01
Petroleum Ether in chrom. column	0.0486 g	3.20E-01 g	6.40E-04	6.21E-01	3.10E-02	8.34E-02
Heat (110 °C 24 h)		2.62E-01 kWh				
Energy to recover solvents		4.26E-02 kWh				
Chemical factory		4.00E-13 unit				

Table 7. Batch approach via CuO nanoparticles - Saha et al. 2009

Inputs	Quantity for 0.186 g of product[5]	Quantity for 1 g of product	Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
N-(2-bromophenyl) benzamide	0.27613 g	1.48E+00 g		9.22E-02	6.80E-03	1.83E-02
Copper Oxide (CuO) Nanoparticles	0.004 g	4.30E-04 g			1.08E-04	1.28E-04
Potassium carbonate (K2CO3)	0.207 g	1.11E+00 g			1.11E+00	
DMSO (1mL)	1.1 g	1.72E+00 g	1.18E-02	1.22E+00	1.65E-01	4.45E-01
Ethyl acetate (20 mL)	18.04 g	2.81E+01 g	1.94E-01	3.54E+01	2.71E+00	7.30E+00
Brine (1x 5mL)	6.01 g	3.23E+01 g	6.46E-02		3.22E+01	
Water (2 x 5 mL)	10 g	5.38E+01 g	1.08E-01		4.83E+01	
Ethyl acetate in chrom. column	0.084 g	4.51E-01 g	9.02E-04	5.71E-01	4.37E-02	1.18E-01
Hexane in chrom. column	0.0609 g	3.28E-01 g	6.55E-04	6.36E-01	3.17E-02	8.54E-02
Heat and stir (110 °C 16 h)		1.24E-01 kWh				
Energy to recover solvents		2.36E-02 kWh				
Chemical factory		4.00E-13 unit				

Table 8. Batch approach via Pyridine-chlorochromate (PCC) - Praveen et al. 2008

Inputs	Quantity for 0.3551 g of product[6]	Quantity for 1 g of product	Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
Schiff's base	0.42628 g	1.20E+00 g		1.84E-01	1.05E-02	2.83E-02
Silica supported PCC	0.47423 g	1.34E+00 g			6.68E-01	2.65E-01
Dichloromethane (10 ml)	13.25 g	1.08E+01 g	7.46E-02	3.54E+00	1.04E+00	2.81E+00
Ethyl acetate (3x20 mL).	54.12 g	4.42E+01 g	3.05E-01	5.57E+01	4.26E+00	1.15E+01
Ethyl acetate in chrom. column	0.160 g	4.51E-01 g	9.02E-04	5.71E-01	4.37E-02	1.18E-01
Petroleum Ether in chrom. column	0.1136 g	3.20E-01 g	6.40E-04	6.21E-01	3.10E-02	8.34E-02
Stir (30 min)		1.95E-02 kWh				
Energy to recover solvents		3.85E-02 kWh				
Chemical factory		4.00E-13 unit				

Table 9. Batch approach via acyl chloride - Wang et al. 2013

Inputs	Quantity for 0.0319 g of product[7]	Quantity for 1 g of product	Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
benzo[d]oxazole (0.2 mmol)	0.02382 g	7.47E-01 g		2.25E-01	1.33E-02	3.57E-02
Acyl chloride (0.4mmol)	0.03140 g	2.85E-01 g	1.97E-03	2.02E-01	2.75E-02	7.40E-02
Potassium carbonate ((0.2 mmol)	0.02764 g	8.66E-01 g			8.66E-01	
PhCl (0.3 mL)	0.3318 g	3.02E+00 g	2.08E-02	4.46E+00	2.91E-01	7.83E-01
H2O (0.1mL)	0.1 g	3.13E+00 g	6.27E-03		2.82E+00	
Ethyl acetate in chrom. column	0.014 g	4.51E-01 g	9.02E-04	5.71E-01	4.37E-02	1.18E-01
Petroleum Ether in chrom. column	0.0102 g	3.20E-01 g	6.40E-04	6.21E-01	3.10E-02	8.34E-02
Heat and stir (140 ºC 12h)		2.87E-01 kWh				
Energy to recover solvents		6.49E-03 kWh				
Chemical factory		4.00E-13 unit				

Inventories for the needed compounds in the synthesis approaches that were not available in life cycle databases

The development of these inventories was based on data from experimental sections in literature. When the yield of the synthesis was not stated, we assumed 95% yields.

Table 10. CPME

Inputs	Quantity for 1 g of product		Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
Cyclopentene	7.16E-01	g	1.43E-03	7.05E-02	3.33E-03	8.97E-03
Methanol	3.37E-01	g	6.73E-04	1.41E-02	1.57E-03	4.22E-03
Sulfuric acid	7.00E-01	g			*5.07E-01	
Heating steam	2.00E-03	MJ				
Electricity	3.33E-04	kWh				
Chemical factory	4.00E-13	unit				
Transport lorry>16t	1.00E-04	tkm				
Transport train	6.00E-04	tkm				

*Neutralized. It goes to water in form of NaSO4

Table 11. H-OMS

Inputs	Quantity for 1 g of product		Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
K-OMS	1.11E+00	g			5.56E-02	5.56E-02
Nitric acid	1.57E+01	g			*2.12E+01	
Deionized water	1.11E+02	g	2.22E-01		9.96E+01	
Heating steam	2.00E-03	MJ				
Electricity	3.33E-04	kWh				
Chemical factory	4.00E-13	unit				
Transport lorry>16t	1.00E-04	tkm				
Transport train	6.00E-04	tkm				

*Neutralized. It goes to water in form of NaNO3

Table 12. K-OMS

Inputs	Quantity for 1 g of product		Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
Manganese sulphate hydrate	1.05E+00	g			5.24E-02	5.24E-02
Nitric acid	5.05E-01	g			*6.81E-01	
Deionized water	6.06E+01	g	1.21E-01		5.45E+01	
Potassium permanganate	6.90E-01	g			6.90E-02	
Heating steam	2.00E-03	MJ				
Electricity	3.33E-04	kWh				
Chemical factory	4.00E-13	unit				
Transport lorry>16t	1.00E-04	tkm				
Transport train	6.00E-04	tkm				

*Neutralized. It goes to water in form of NaNO3

Table 13. DDQ

Inputs	Quantity for 1 g of product[8]		Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
2,3-dicyanohydroquinone (DCH)	7.80E-01	g		1.04E-01	7.25E-03	1.95E-02
Water	5.46E+00	g	8E-13	4.91E-01	4.91E+00	
Concentrated nitric acid (70%)	1.47E+00	g			*2.83E+00	
Concentrated hydrochloric acid (30%)	6.49E+00	g			**1.04E+01	
Carbon tetrachloride	8.00E-01	g			8.00E-01	
Heating steam	2.00E-03	MJ				
Electricity	3.33E-04	kWh				
Chemical factory	4.00E-13	unit				
Transport lorry>16t	1.00E-04	tkm				
Transport train	6.00E-04	tkm				

*Neutralized. It goes to water in form of NaNO3. **Neutralized. It goes to water in form of NaCl

Table 14. Phosphonium acidic ionic

Inputs	Quantity for 1 g of product[3]		Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
Triphenylphosphine	4.74E-01	g		2.73E-02	1.38E-03	3.72E-03
1,4-butane sultone	2.46E-01	g		6.08E-03	7.18E-04	1.93E-03
Toluene solvent	2.51E+00	g	5.03E-03	5.33E+00	2.43E-01	6.55E-01
p-toluenesulfonic acid	3.11E-01	g		1.06E-02	9.02E-04	2.43E-03
Diethyl ether	2.07E+01	g	4.14E-02	3.11E+01	2.00E+00	5.39E+00
Heating steam	2.00E-03	MJ				
Electricity	3.33E-04	kWh				
Chemical factory	4.00E-13	unit				
Transport lorry>16t	1.00E-04	tkm				
Transport train	6.00E-04	tkm				

Table 15. DABCO (triethylenediamine)

Inputs	Quantity for 1 g of product[9]		Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
Ethylamine	1.26E+00	g	2.53E-03	2.71E-01	5.31E-03	1.43E-02
ZSM-5 (Zeolita Socony Mobil – 5)	8.86E-01	g			4.43E-02	
Ethyl acetate (10 mL)	2.62E+00	g	5.23E-03	3.31E+00	2.53E-01	6.82E-01
Heating steam	2.00E-03	MJ				
Electricity	3.33E-04	kWh				
Chemical factory	4.00E-13	unit				
Transport lorry>16t	1.00E-04	tkm				
Transport train	6.00E-04	tkm				

Table 16. Ru2Cl4(CO)6

Inputs	Quantity for 1 g of product[10]		Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
RuCl3	8.51E-01	g			4.09E-02	
CO	3.44E-01	g	1.59E-02			
2-metoxietanol	2.32E-01	g	4.64E-04	2.55E-01	2.25E-02	6.05E-02
Heating steam	2.00E-03	MJ				
Electricity	3.33E-04	kWh				
Chemical factory	4.00E-13	unit				
Transport lorry>16t	1.00E-04	tkm				
Transport train	6.00E-04	tkm				

Table 17. N-(2-bromophenyl)benzamide

Inputs	Quantity for 1 g of product[11]		Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
Benzoyl fluoride	4.73E-01	g		3.73E-02	2.29E-03	6.17E-03
2-bromoaniline	6.56E-01	g		3.19E-02	3.18E-03	8.55E-03
Chlorobenzene	3.21E+00	g		4.78E+00	3.11E-01	8.38E-01
Heating steam	2.00E-03	MJ				
Electricity	3.33E-04	kWh				
Chemical factory	4.00E-13	unit				
Transport lorry>16t	1.00E-04	tkm				
Transport train	6.00E-04	tkm				

Table 18. Copper Oxide (CuO) Nanoparticles

Inputs	Quantity for 1 g of product[12]		Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
CuSO4	2.11E+00	g			2.46E-02	2.93E-02
Citric acid	2.55E+00	g		1.15E-01	1.28E-02	3.44E-02
Deionized water	5.09E+01	g	1.02E-01		4.58E+01	0.00E+00
Ethylene glycol	3.00E+00	g	6.00E-03	1.21E+00	2.90E-01	7.82E-01
Heating steam	2.00E-03	MJ				
Electricity	3.33E-04	kWh				
Chemical factory	4.00E-13	unit				
Transport lorry>16t	1.00E-04	tkm				
Transport train	6.00E-04	tkm				

Table 19. Schiff base

Inputs	Quantity for 1 g of product[6]		Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
Salicylaldehyde (20.0 mmol)	6.03E-01	g		5.56E-02	2.95E-03	7.93E-03
o-aminophenol (30.0 mmol)	8.08E-01	g		1.76E-01	2.88E-02	7.75E-02
Methanol (10 mL)	5.66E-01	g	1.13E-03	4.94E-01	5.48E-02	1.48E-01
Ice-cold methanol (5 mL)	2.83E-01	g	5.66E-04	2.47E-01	2.74E-02	7.38E-02
Heating steam	2.00E-03	MJ				
Electricity	3.33E-04	kWh				
Chemical factory	4.00E-13	unit				
Transport lorry>16t	1.00E-04	tkm				
Transport train	6.00E-04	tkm				

Table 20. Silica supported PCC

Inputs	Quantity for 1 g of product[6]		Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
Silica gel 100-200 mesh	4.68E+00	g			1.17E-02	8.82E-02
Pyridine-chlorochromate (PCC)	1.05E+00	g		4.09E-02	5.11E-03	1.37E-02
Acetone (200 mL)	1.07E+00	g	2.15E-03	1.55E+00	1.04E-01	2.80E-01
Heating steam	2.00E-03	MJ				
Electricity	3.33E-04	kWh				
Chemical factory	4.00E-13	unit				
Transport lorry>16t	1.00E-04	tkm				
Transport train	6.00E-04	tkm				

Table 21. Pyridine-chlorochromate (PCC)

Inputs	Quantity for 1 g of product[13]		Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
CrO3	5.53E-01	g			4.46E-02	4.46E-02
HCl	2.22E-01	g			5.25E-02	
Pyridine	4.38E-01	g	8.75E-04	1.23E-01	6.76E-03	1.82E-02
Heating steam	2.00E-03	MJ				
Electricity	3.33E-04	kWh				
Chemical factory	4.00E-13	unit				
Transport lorry>16t	1.00E-04	tkm				
Transport train	6.00E-04	tkm				

Table 22. Benzo[d]oxazole

Inputs	Quantity for 1 g of product[7]		Process air emissions (g)	Wastewater treatment emissions (g)		
				CO_2 to air	Compound to river	Sludge to landfill
N-(2-bromophenyl)formamide	1.77E+00	g		8.64E-02	8.57E-03	2.31E-02
CuO	4.00E-02	g			1.00E-02	1.19E-02
K2CO3	2.00E+00	g	4.00E-03		2.00E+00	0.00E+00
Heating steam	2.00E-03	MJ				
Electricity	3.33E-04	kWh				
Chemical factory	4.00E-13	unit				
Transport lorry>16t	1.00E-04	tkm				
Transport train	6.00E-04	tkm				

REFERENCES

1 F. Ferlin, M. K. Van Der Hulst, L. Vaccaro and S. Santoro, *Green Chem.*, 2019, **21**, 5298–5305.

2 J. Chang, K. Zhao and S. Pan, *Tetrahedron Lett.*, 2002, **43**, 951–954.

3 Q. T. Nguyen, A. H. Thi Hang, T. L. Ho Nguyen, D. K. Nguyen Chau and P. H. Tran, *RSC Adv.*, 2018, **8**, 11834–11842.

4 A. Khalafi-Nezhad and F. Panahi, *ACS Catal.*, 2014, **4**, 1686–1692.

5 P. Saha, T. Ramana, N. Purkait, M. A. Ali, R. Paul and T. Punniyamurthy, *J. Org. Chem.*, 2009, **74**, 8719–8725.

6 C. Praveen, K. H. Kumar, D. Muralidharan and P. T. Perumal, *Tetrahedron*, 2008, **64**, 2369–2374.

7 L. Wang, X. Ren, J. Yu, Y. Jiang and J. Cheng, *J. Org. Chem.*, 2013, **78**, 12076–12081.

8 D. Walker and T. D. Waugh, *J. Org. Chem.*, 1965, 30.

9 BASF SE, *Process for the preparation of pure triethylenediamine (TEDA). Patent US6552194B2*, United States, 2002.

10 J. A. Cabeza, M. A. Martinez-Garcia, V. Riera, D. Ardura, S. Garcia-Granda and J. F. Van der Maelen, *Eur. J. Inorg. Chem.*, 1999, **2**, 1133–1139.

11 Chemsink, Synthesis of N-(2-bromophenyl)benzamide via Nucleophilic Acylation, http://www.chemsink.com/reaction/300174/, (accessed 31 August 2021).

12 P. Reyes, *Síntesis y caracterización de nanopartículas de cobre y óxido de cobre y su incorporación en una matriz polimérica y el estudio de sus propiedades anti bacterianas (Thesis in Spanish*, Coahuila, Mexico, 2012.

13 G. Piaimcatelli, A. Scettri and M. D'Auria, *Synthesis (Stuttg).*, 1982, **4**, 245–258.