

Supplementary materials

# Removal of Pesticides from Waters by Adsorption: Comparison between Synthetic Zeolites and Mesoporous Silica Materials. A Review

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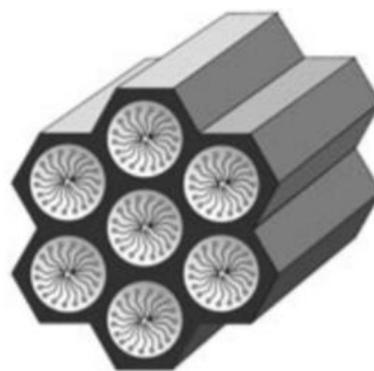
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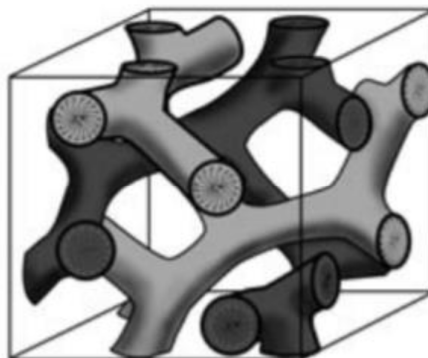


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MCM-41



MCM-48

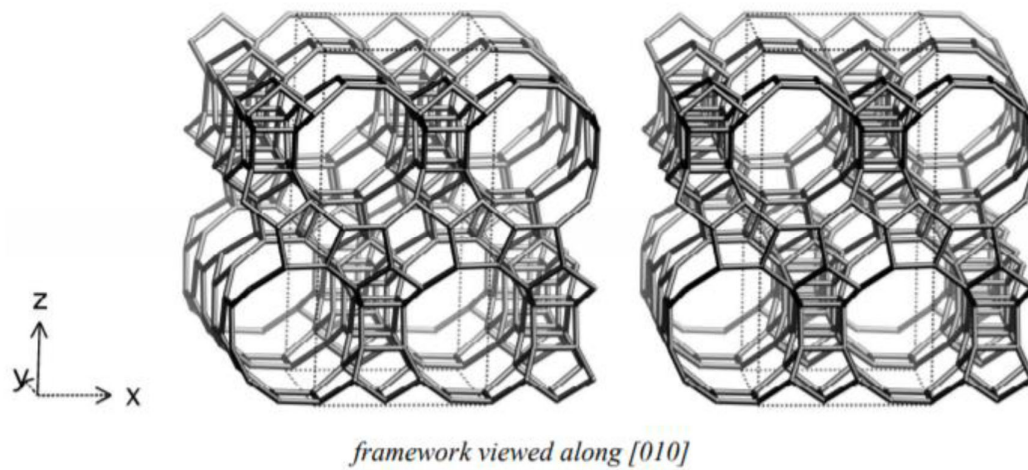


SBA-15

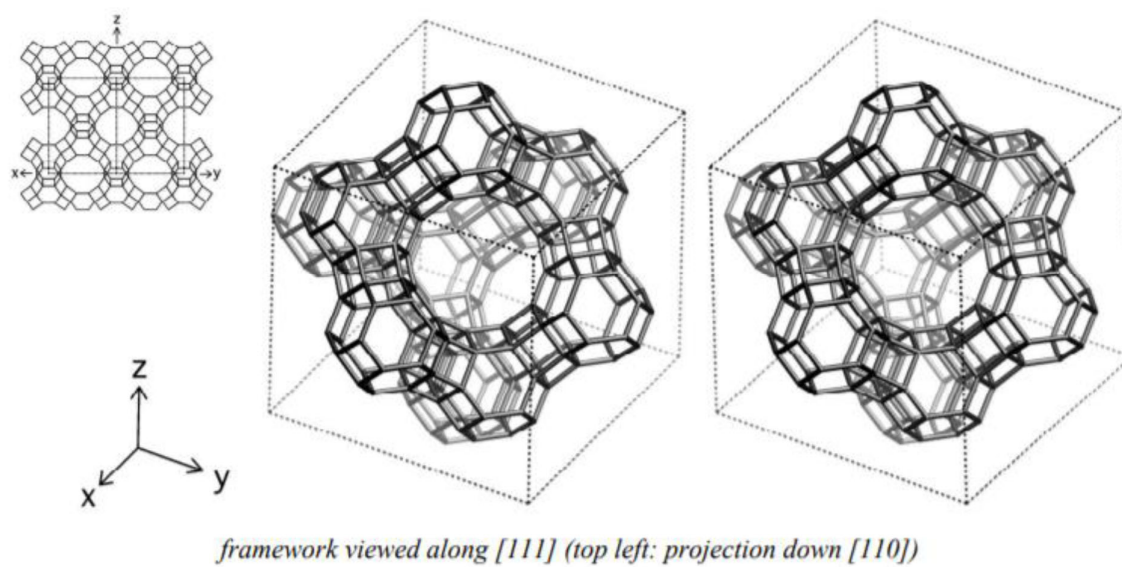


**Figure S1.** Structures of mesoporous silica materials.

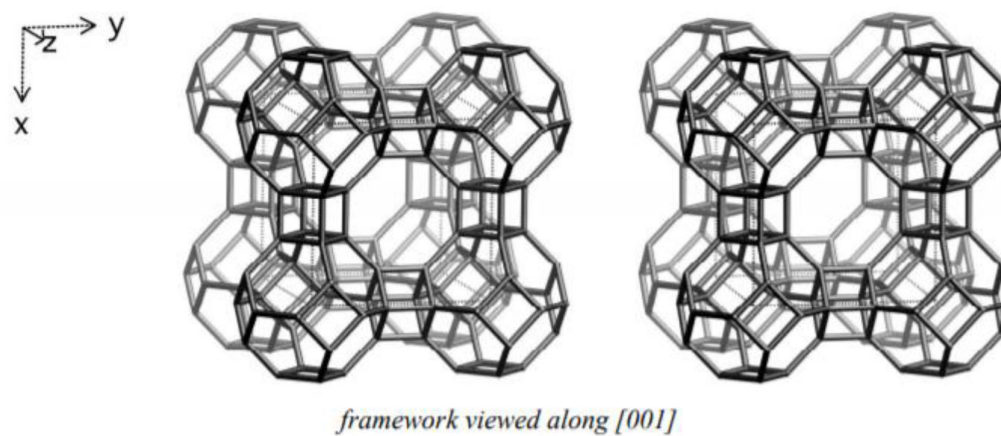
BEA

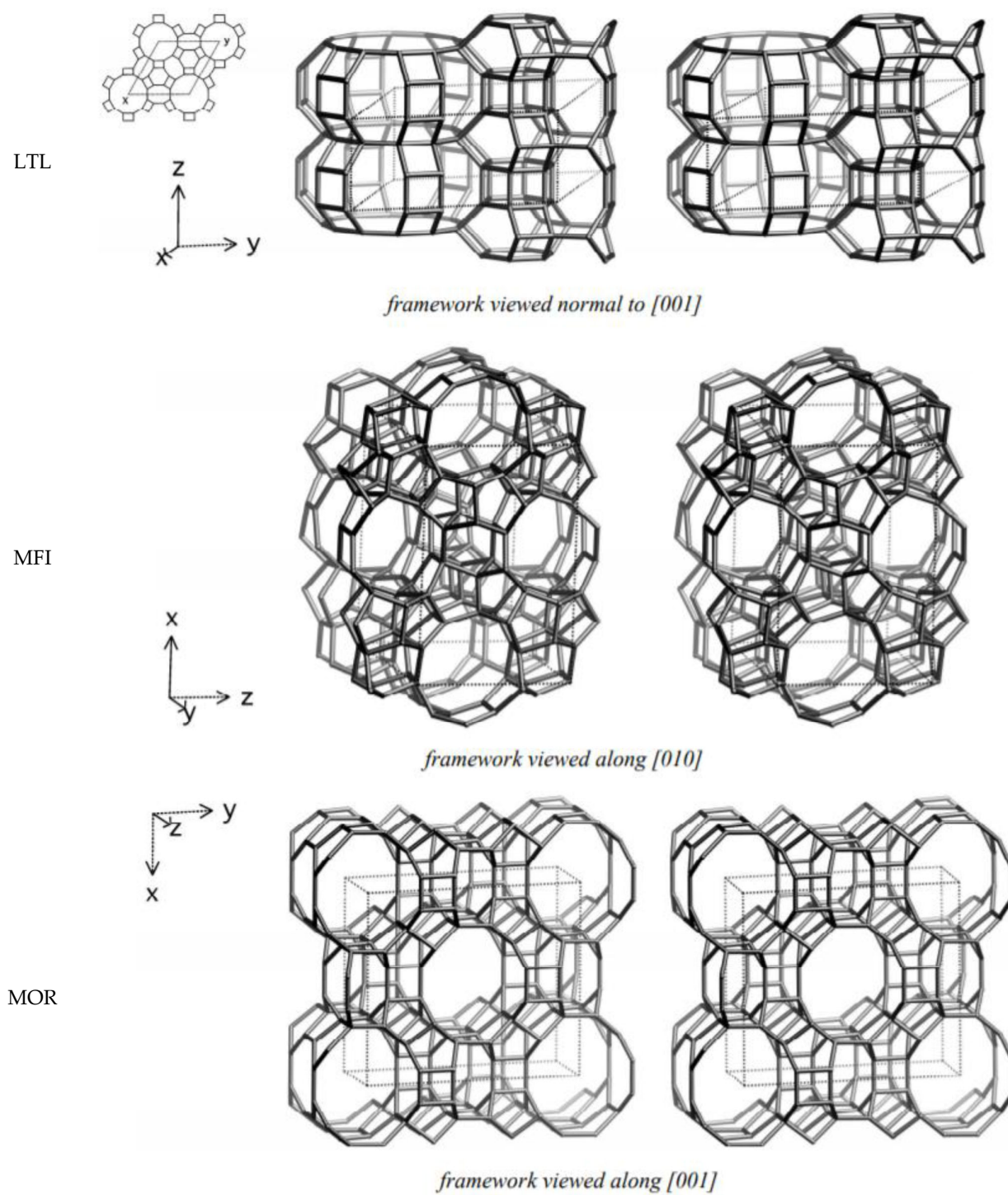


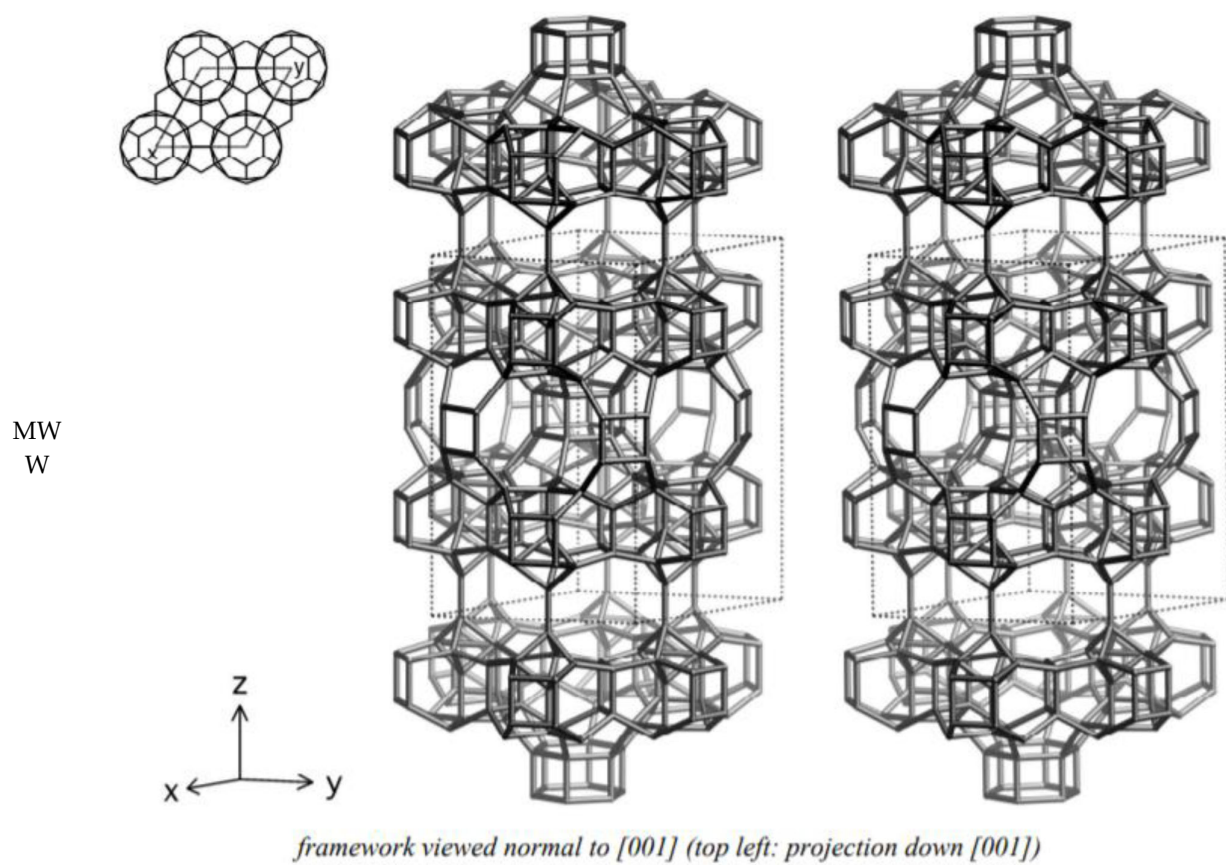
FAU



LTA







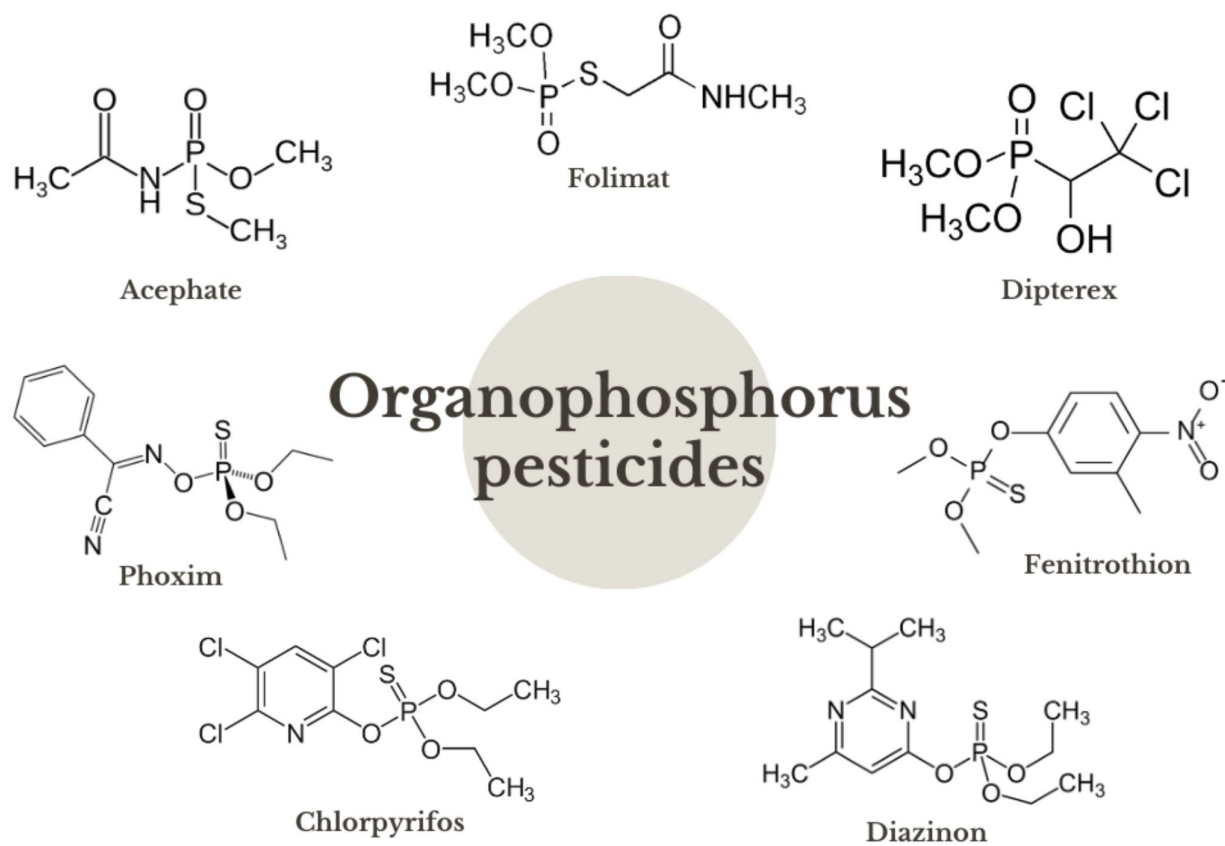
**Figure S2.** Framework types of selected zeolites. Zeolites X and Y mentioned in the manuscript have FAU framework type, zeolite A – LTA, zeolite ZSM5 – MFI, zeolite MCM-21 – MWW.



The image displays the chemical structures of seven organochlorine pesticides, arranged around a central orange circle containing the text "Organochlorine pesticides".

- Pentachlorophenol**: A benzene ring with a hydroxyl group (-OH) and five chlorine atoms (-Cl) at the 2, 3, 4, 5, and 6 positions.
- DDT**: 1,1,1-tris(4-chlorophenyl)ethane. It consists of a central carbon atom bonded to three 4-chlorophenyl groups and one hydrogen atom.
- Heptachlor**: A bicyclic structure with seven chlorine atoms.
- Methoxychlor**: 1,1,1-tris(4-methoxyphenyl)ethane. It consists of a central carbon atom bonded to three 4-methoxyphenyl groups and one hydrogen atom.
- Dieldrin**: A complex polycyclic structure with eight chlorine atoms.
- Endosulfan**: A bicyclic structure with six chlorine atoms and a sulfonate group (-SO<sub>2</sub>-O-).
- Aldrin**: A bicyclic structure with six chlorine atoms.

**Figure S3.** Structures of organochlorine pesticides.



**Figure S4.** Structures of organophosphorus pesticides.

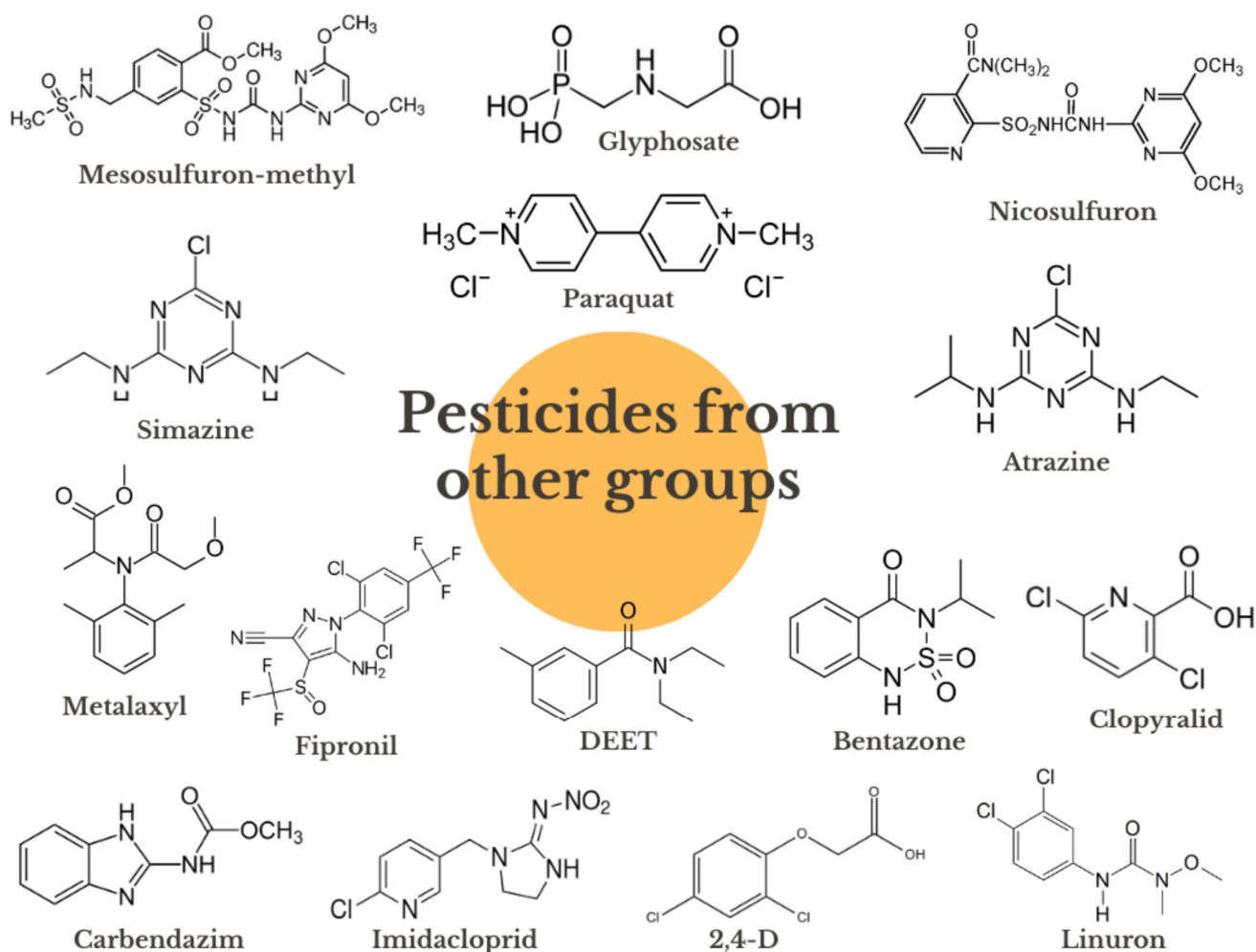


Figure S5. Structures of pesticides from other groups.

**Table S1.** Selected adsorption capacities and other parameters for the removal of organochlorine pesticides by mesoporous silica materials.

Adsorbate	Adsorbent	Adsorption		Conditions					Reference
		(%)	(mg/g)	Conc. range <sup>1</sup> (mg/L)	pH (-)	Time (h)	Temperature (°C)	Adsorb. dosage <sup>2</sup> (g/L)	
DDT	SBA-15	99	5.66*	8		12			
	MCM-41	92	0.68*						
	MCM-48	89.5	0.66*	1.03	-	36	-	1.4	[100]
	HMS	93.5	0.69*						
DDT		98	-						
DDD	SBA-15	99	-						
DDE		96	-						
DDT		94–97	-	4	-	12	20	-	[99]
DDD	Fe-SBA-15	98–99	-						
DDE		98	-						
Pentachlorophenol	SBA-15	5.8	5.79						
	SA-SBA-15	32.8	3.28	10	6.5	12	25	4	[51]
	ST-SBA-15	24.6	2.46						
Pentachlorophenol	(Na)Al-MCM-41	37.71*	33						
	(K)Al-MCM-41	40*	35						
	(Cu)Al-MCM-41	53.71*	47	700	6	4	30	8	[97]
	(Cr)Al-MCM-41	53.71*	47						
Heptachlor	HMS	52.56*	0.027	0.075					
Endosulfan		85.51*	0.041	0.070					
Aldrin		60.65*	0.027	0.065					
Dieldrin		41.15*	0.031	0.110					
DDT		63.71*	0.024	0.055				1.46	
DDD		61.18*	0.044	0.105					
DDE		75.43*	0.031	0.060					
Methoxychlor		57.28*	0.051	0.130					
Heptachlor	CD-HMS-2%	66.27*	0.035	0.075		24	4		[98]
Endosulfan		42.60*	0.021	0.070					
Aldrin		69.91*	0.032	0.065					
Dieldrin		54.22*	0.042	0.110					
DDT		64.55*	0.025	0.055				1.42	
DDD		71.68*	0.053	0.105					
DDE		82.83*	0.035	0.060					
Methoxychlor		68.82*	0.063	0.130					
DDT	HMS	37.77*	2.77						
	Fe <sub>3</sub> O <sub>4</sub> @HMS-2	102.27*	7.5	2.2	-	1	room	0.3	[101]

\*—values calculated based on the data published in the cited articles; <sup>1</sup>—concentration range; <sup>2</sup>—adsorbent dosage.



**Table S2.** Selected adsorption capacities and other parameters for the removal of organophosphorus pesticides by mesoporous silica materials.

[illegible]

Acephate		0	0*						
Folimat		1.6	0.00016*						
Phoxim	MCM-48	4.4	0.00044*						
Chlorpyrifos		4.9	0.00049*						
Dipterex		10	0.0001*						
Diazinon	MCM-41	80	256*	320				1	
Fenitrothion		100	56*	280	-	24	room	5	[103]
Diazinon	MCM-48	75	240*	320				1	
Fenitrothion		67	37.52*	280				5	
Diazinon	MCM-41	55	9						
	MPS-MCM-41	68	11	50	9	1	25	3	[102]

\*— values calculated based on the data published in the cited articles; <sup>1</sup>— concentration range; <sup>2</sup>— adsorbent dosage.



	Cu-MCM-41	7*	140						
	Zn-MCM-41	7.55*	151						
	MCM-41	0*	0						
2,4-D	0.24APTES-MCM-41	75*	132	440	4.5	6	25	2.5	[105]
Paraquat	HMS	54.08*	23.81	275.16	9.5	1	25	6.25	[116]

\*—values calculated based on the data published in the cited articles; 1—concentration range; 2—adsorbent dosage.

**Table S4.** Selected adsorption capacities and other parameters for the removal organochlorine and organophosphorus pesticides by synthetic zeolites.

Adsorbate	Adsorbent	Adsorption		Conditions				Adsorb. dos- age <sup>2</sup> (g/L)	Reference
		(%)	(mg/g)	Conc. range <sup>1</sup> (mg/L)	pH (-)	Time (h)	Temperature (°C)		
$\alpha$ -endosulfan	HY(40)	-	775	30	-	1	room	-	[121]
	HBEA (Cal)	-	360						
	St700(3)	-	650						
Acephate	NaY	7.9	0.00079*	0.1	7	12	room	10	[104]
Folimat		3.4	0.00034*						
Phoxim		5.6	0.00056*						
Chlorpyrifos		11.0	0.0011*						
Dipterex		15.1	0.00151*						
Acephate	FeNaY (imp-3.5%)	7.6	0.00076*						
Folimat		17.9	0.00179*						
Phoxim		31.8	0.00318*						
Chlorpyrifos		31.4	0.00314*						
Dipterex		93.4	0.00934*						
Acephate	FeY (ex-8.6%)	20.6	0.00206*						
Folimat		18.3	0.00183*						
Phoxim		19.1	0.00191*						
Chlorpyrifos		19.5	0.00195*						
Dipterex		31.9	0.00319*						
Acephate	NTY	4.0	0.0004*						
Folimat		1.9	0.00019*						
Phoxim		10.7	0.00107*						
Chlorpyrifos		27.0	0.0027*						
Dipterex		13.3	0.00133*						
Acephate	MCM-22	8.0	0.0008*						
Folimat		3.9	0.00039*						
Phoxim		20.7	0.00207*						
Chlorpyrifos		30.8	0.00308*						
Dipterex		16.7	0.00167*						

\*— values calculated based on the data published in the cited articles; <sup>1</sup>— concentration range; <sup>2</sup>— adsorbent dosage.

**Table S5.** Selected adsorption capacities and other parameters for the removal of different groups of pesticides by synthetic zeolites.

Adsorbate	Adsorbent	Adsorption		Conditions				Adsorb. dos- age <sup>2</sup> (g/L)	Reference
				Conc. range <sup>1</sup> (mg/L)	pH (-)	Time (h)	Temperature (°C)		
2,4-D	HY	3.2*							
	10HHY								
	10SHY								
	NaY				3				
	10HNaY			250		24	28	1	[106]
	10SNaY								
Paraquat	HY								
	30SHY								
	NaY				11				
	30SNaY								
Paraquat	NaY	64.24*	185	720	-	1	room	2.5	[115]
	NaBEA	42.36*	122						
Carbendazim	NaY	4.5	0.00045*						
Imidacloprid		0	0*						
Carbendazim	FaNaY (imp-3.5%)	12.0	0.0012*						
Imidacloprid		7.9	0.00079*						
Carbendazim	FeY (ex-8.6%)	20.2	0.00202*	0.1	7	12	room	10	[104]
Imidacloprid		21.5	0.00215*						
Carbendazim	NTY	74.9	0.00749*						
Imidacloprid		13.3	0.00133*						
Carbendazim	MCM-22#	100	0.01*						
Imidacloprid		1.9	0.00019*						
Paraquat	NAX	41.67*	120	720	-	1	room	2.5	[114]
Fipronil	H-ZSM-5	30	270*						
	Ce25ZSM-5	79.6	716.4*	900	2	2	25	1	[122]
	Ce30ZSM-5	76.7	690.3*						
Bentazone	beta (BEA)-1	69.6	1.39*						
Clopyralid		9.1	0.18*						
Imidacloprid		98.8	1.98*						
Metalaxyl-m		42.0	0.84*						
Bentazone	Y (FAU)-7	100	2	10	-	-	22	5	[120]
Clopyralid		10.8	0.22*						
Imidacloprid		99.7	1.99*						
Metalaxyl-m		99.3	1.99*						
Bentazone	4A (LTA)-11	0.2	0.004*						



Clopyralid		0	0*						
Imidacloprid		0	0*						
Metalaxyl-m		64.6	1.29*						
Bentazone		21.7	0.43*						
Clopyralid	ZSM-5/silicalite-1	3.9	0.08*						
Imidacloprid	(MFI)-14	86.1	1.72*						
Metalaxyl-m		36.9	0.74*						
Paraquat	H_LTL	10.4*	26	500	11	24	30	2	[117]
	K_LTL#	66.8*	167						

\*—values calculated based on the data published in the cited articles; <sup>1</sup>—concentration range; <sup>2</sup>—adsorbent dosage.



	ZSM-5/silicalite-1 (MFI)-14	86.1	1.72*						
Mesosulfuron-methyl	HZSM-5	36*	3.6						
	HZSM-5-60	41*	4.1						
	HZSM-5-60-Ac	44*	4.4	20	6	72	25	2	[108]
	HMOR	0*	0						
	HMOR-70	29*	2.9						
	HMOR-70-Ac	41*	4.1						
Nicosulfuron	Z30	17.33*	6.5						
	Z30K/PW-D	22.66*	8.5						
	Z30PW/K-C	28*	10.5	75	5	24	23	2	[132]
	Z30PW/K-D	32*	12						
	Z30K/PW-C	76*	28.5						

\*—values calculated based on the data published in the cited articles; <sup>1</sup>—concentration range; <sup>2</sup>—adsorbent dosage.

**Table S7.** Selected adsorption capacities and other parameters for the removal of glyphosate-based pesticides by synthetic zeolites.

Adsorbate	Adsorbent	Adsorption		Conditions				Adsorb. dosage <sup>2</sup> (g/L)	Reference
				Conc. range <sup>1</sup> (mg/L)	pH (-)	Time (h)	Temperature (°C)		
Glyphosate	BEA	4.31*	34.5	4000	-	24	23	5	[110]
	BKPW-2	7.11*	56.9						
	BKPW-3	7.73*	61.8						
	BKPW-2C	11.53*	92.2						
	BKPW-3C	10.18*	81.4						
Glyphosate	HZSM-5	3.73*	14.9	4000	1.7	2	-	10	[111]
	PZ 1/1	6.70*	26.8						
	PZ 1/5	8.43*	33.7						
	PZ 1/10	4.63*	18.5						
	PZ 1/1 S	6.6*	26.4						
	PZ 1/1 d	15.48*	61.9						
Glyphosate	PZ 1/1 Sd	14.08*	56.3	100	3	2	-	2	[112]
	4A	76*	38						
	Cu-4A	80*	40						

\*— values calculated based on the data published in the cited articles; <sup>1</sup>— concentration range; <sup>2</sup>— adsorbent dosage.#