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b t
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ABSTRACT

( ) b t (-) t t t ( )
y t z t . t fitt
t . y y t t t t -
t - t t t 2 8 338 t t
b b tt by t t t .
t t t t y b t t tt t 3 2– t
t fl t t t t ty. -
yz by (t t y), t ( )
t (y - y) - y t t y( )t ,
t y. t t fi t t y y t b t -
by t . - t fi fi ty t t b b t
t t - y t b b t t b t .
fi ,
2016 . . t .

1. Introduction

( ) y t t t t t t
1]. t y t t 2]. ,t t y
t t t t t
t t t

Table 1

(t.%).

3.	81.0	11.	1.5	20.	3.3	17.6	2.7

t . 18].

, t t b t t t z t

t

y, t b t y t

b t by t t t t t ty

t . , t z t t by-

t y t t t t t b ty

t . y t b t , -

fi t t t t t b t

2,12,16,24].

, t t t (. . —)

, t t — , ,

b y fi t . t t t

y t b -

t . , t t b b

b t t t t b t 25–2].

t t t t t -

( ), ( ), ( ), ( ) t b

t , b t b t 14,17,30,31].

t t , y ( ) b -

t t t t b t b

fi ty t y t b ty t

32]. t y t t -

t t t t t y z t y

t t b t - 32,33].

, t t t, b z z (2)

by t- t t , b

b t ( ) t t t .

t b t t fi t t z -

b t t

.

t , t b ty 2- b -

b t(-) b t t t

t b t t . b t

t , t t t b

, t t t t t t

t . t , t y t

by - , t -

. t y t y t t

t b b by- t t b -b t t (-

b t).

2. Materials and methods

2.1. Materials

b t ( ) t t

t y by t b b t t t by

y b b - y ., t . ( ) t t

t fi t . y t 81.0 t.% ,

11. t.% , 3. t.% 18], t t

b 1. ((3 7)4) -

t ., t .

t t t fi t . t t t -

t 2 4, , 3, 4, 3, 2 3, ,

yt bt .

2.2. Preparation of lignocellulosic butanol residue loading Zr(IV) (LBR-Zr)

t y 50 fl

t t t . 1.0

20 t t t t t b t -

. fl t t

t 110 . 1.5 70% z ((3 7)4) -

t y t b t

t 3 t t . t t

fi y t t t n- , t -

y by y t z t .

t t t t t

, t t t t -

bt - t .

2.3. Adsorption studies

t t t t b t t

t 2 8 . t t y 2 4

t t t t t (1000 −1)

t t t t t t .

t t t t t (6.0 ± 0.2),

t t 0.1 −1 0.1 −1

t . t t , t -

t t fi t t 0.45-μ b fi t

t t t t t t t t

by yb t b t t .

t t , t t

t t t fi t b .

t ty t

$$q_e = \frac{(C_0 - C_e)V}{m} \quad (1)$$

q_e (−1) t b t t, C_0

(−1) t t t t C_e (−1) t

b t t , V( ) t t , m( )

t b t .

t t t t - t

t 2 8 , t t t 5, 10 20 −1

t 6.0 ± 0.2 t y. t fi t t , b t

1.0–2.0 t t t t t t

t y t t t t .

(2–8) y t t t t

40 −1 t t t t t 2 8 . t

t t t by 20 −1 t t t -

t t t t t (2 8, 318 338).

(−, 3−, −, 4 2−, 3 2− 3−) t

t t 300 −1 t t t t

2 8 fi t t t 40 −1 t

t , t t 6.0 ± 0.2.

2.4. Adsorbent characterization

2.4.1. X-ray photoelectron spectroscopy (XPS) analysis

, - - (t

t t) t t t

5000 b t t (250

t .), t t t fitt t

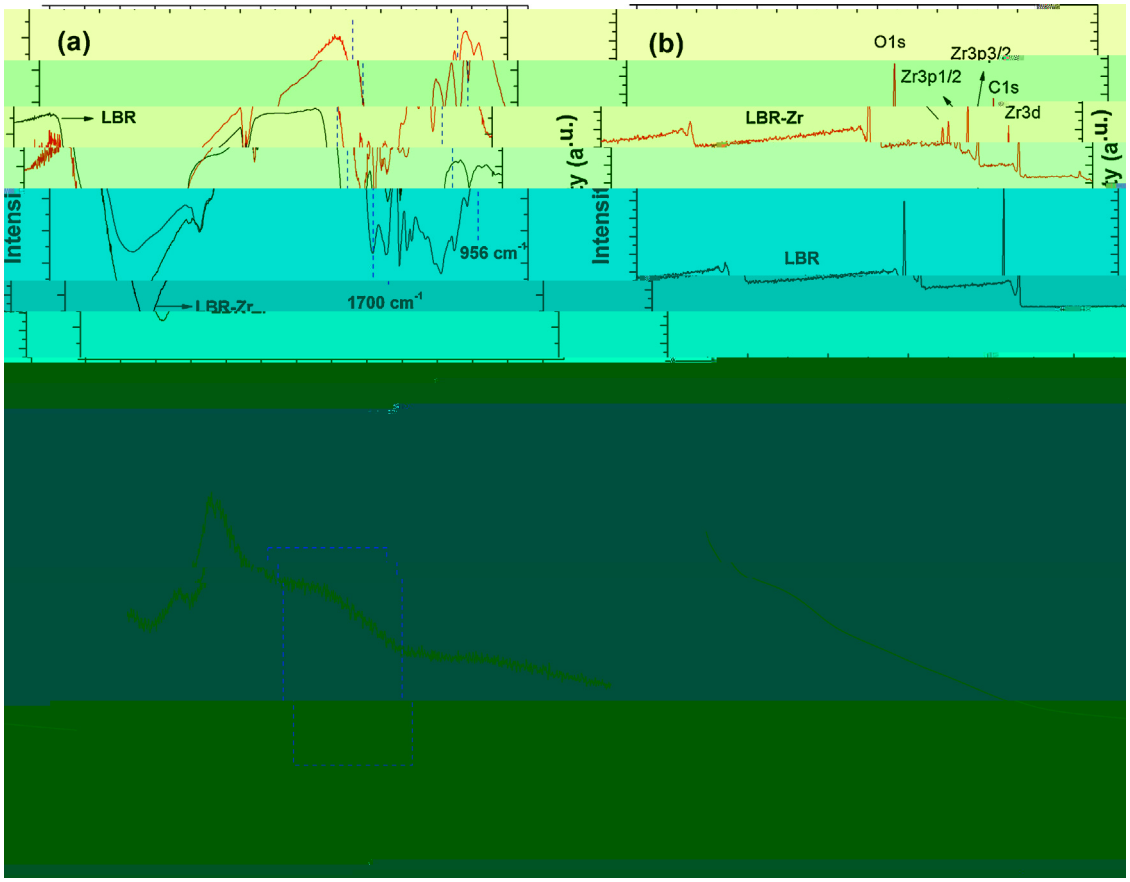


Fig. 1. ( ) (b), ( ) ( ) t - , t y.

Table 2
t t t t t b b t.

	2 t t (%)	(2 −1)	(3 −1)
b	–	16.38	0.042
-	6. 6	76.38	0.167

t by .

41 7.5 y . 1 t 284.6 . t t - y , , t t y.

t t , tt - t t .

2.4.2. Fourier transform infrared (FTIR) analysis

t , - - (t t) 1100 t t 4000–400 −1 t t .

2.4.3. X-ray diffractomer (XRD) analysis

t t - bt / - t α t 2θ 10–60° t 5° −1.

2.4.4. Scanning electron microscopy (SEM) examination with energy-dispersive-X-ray spectroscopy (EDX) analysis

y , - - (t - t) t t -4800 fi t t ( ) t y - y y ( ) t -

2.4.5. Thermogravimetric analysis (TGA)

t

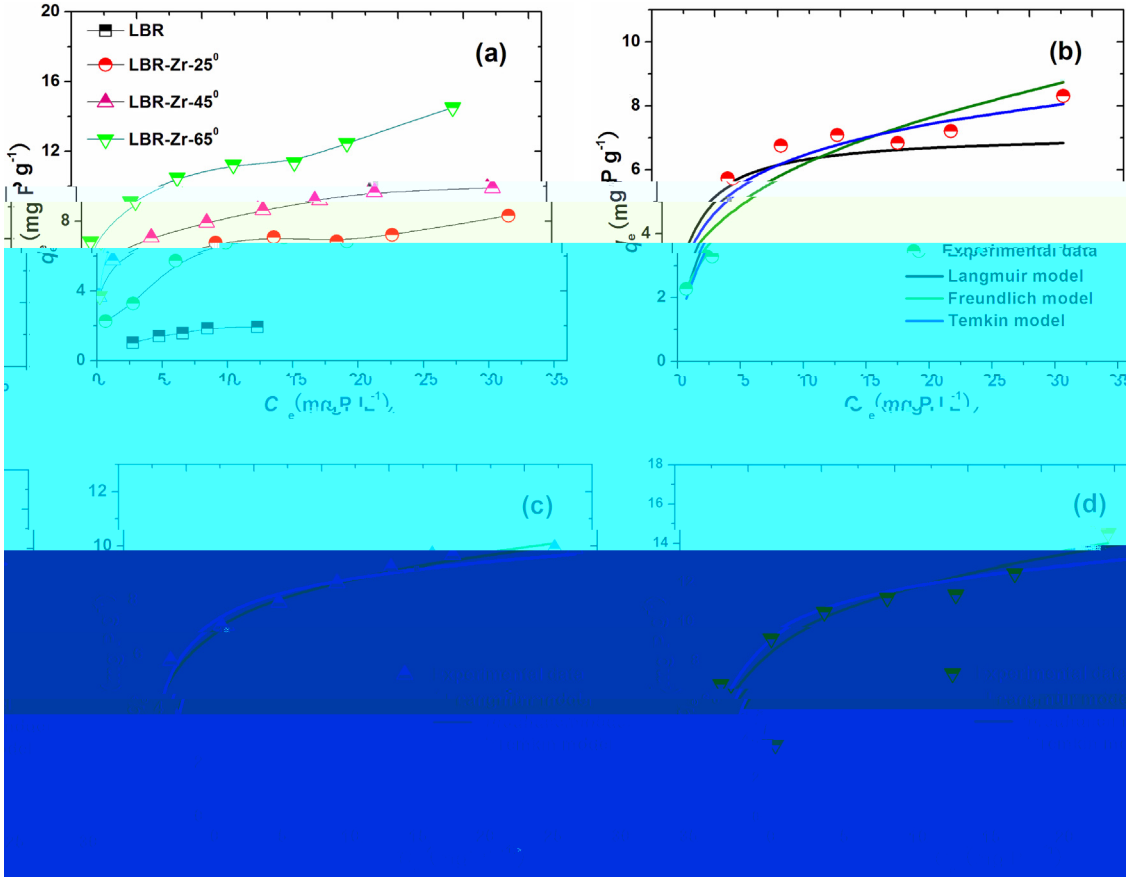


Fig. 2. t - t 25 °, 45 ° 65 ° t 25 ° ( ) t b t t t t bt t t fitt - t 25 ° (b), t 45 ° ( ) t 65 ° ( ). (b b b t = 0.625 −1, = 6.0 ± 0.2, b t = 48 .)

Table 3
b t t bt , t t t b b t t - .

t ( )	t t	t t	t t
	b (−1) (−1) 2	2	2
- 2 8	0.64 7.17 0.8 5	2.6414 2. 1 0. 442	2.5673 1.5766 0. 445
318	4.51 8.42 0. 054	5.2688 5.32 0. 32	5.5705 1.1 41 0. 800
338	2.13 11.78 0. 7 0	6.2336 4.16 0. 510	6.8135 1.8 21 0. 5

3.2. Structure characterization analysis of LBR-Zr

y t - t b 2. t b t - t b - . fi t t b t t 16.38 2 −1 76.38 2 −1 - t y t t 2 b z b . t t - t 0.042 3 −1 0.167 3 −1 , fl t t t t t t . t t 2 6. 6% . b z b z t fi by t , , , , . t t - t . 1 . t t , t b t 1651, 1500 1410 −1 t t t b t t 56 −1 t t - , fi t

Table 4

LBR (UM)	**1.92**	**his study**
	0.286	. 46]
	0.836	. 47]
	1.10	. 48]
	0.8	. 12]
	4.35	. 4]
LBR-Zr (M)[b]	**8.75**	**is study**
	4.785	. 12]
	4.30	
	5.10	
	14.4	
	57	
	20.35	
	13. 4	. 31]

fi
[b] fi

600 °, 58.8% 2 .

2

3.3. Adsorption isotherm

fit 42]. 43], 43],

$$q_e = \frac{Q_0 b C_e}{1 + b C_e} \quad (2)$$

44].

$$q_e = K_F C_e^{1/n} \quad (3)$$

45].

$$q_e = A + B\,C \quad (4)$$

2 8, 318 338 = 6.0 ± 0.2 (2). fitt 2

t 318 0. 054, 0. 32, 0. 800, . 2). 30].

Table 5

t (2 8, 318 338).

2 8			0.178
318			
338	−10.372		

t (8.75 −1), t

(1. 2

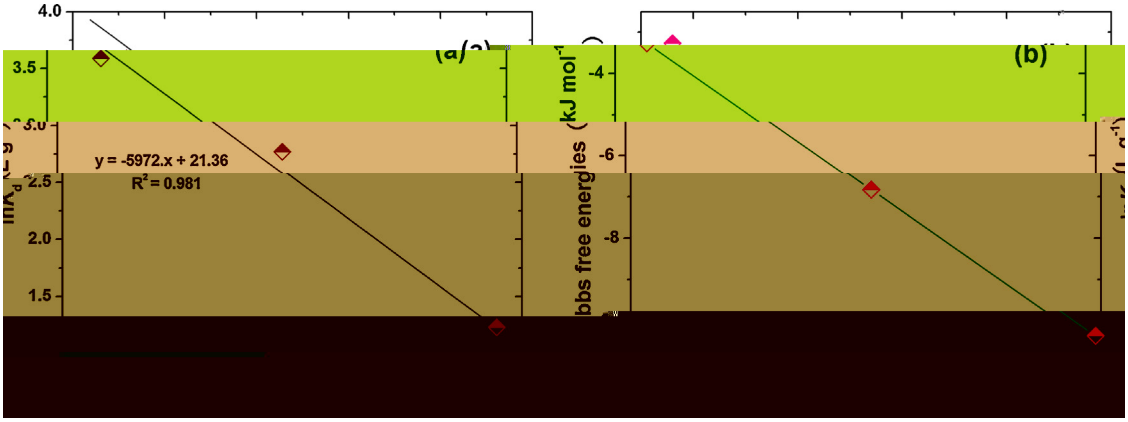


Fig. 3. 1/T ($^{-1}$) k t t t y t by - ( ) ΔG° T (b).

Table 6
t t t t - t t t t (5, 10 20 $^{-1}$).

t t ($^{-1}$)							t ($^{-1}$)
	q ($^{-1}$)	k_1($^{-1}$)	^{2}	q ($^{-1}$)	k_2 ($^{-1}$ $^{-1}$)	^{2}	
5	1. 8	0.006	0.837	4.34	0.0283	0.	4.43
10	3.84	0.00 2	0. 48	6.45	0.0112	0.	6.42
20	5.05	0.006	0. 41	8.62	0.0075	0.	8. 0

^{2} = fi t .

t t . t y t , z., t y (ΔG°), y (ΔS°) t y (ΔH°) t by t t bt t t t (2 8, 318 338) (5)–(7). t . K t t b fi t - b t, by t b (q) b (C) 45,51,52] R t t t (8.314 J $^{-1}$ $^{-1}$) T t t ( ) ΔS° t t y (J $^{-1}$ $^{-1}$) ΔH° t t y (J $^{-1}$), t y.

$$\Delta G^{\circ} = -RT \ln K \tag{5}$$

$$\Delta G^{\circ} = \Delta H^{\circ} - T\Delta S^{\circ} \tag{6}$$

$$\ln K_d = \frac{\Delta S^{\circ}}{R} - \frac{\Delta H^{\circ}}{RT} \tag{7}$$

(5)–(7), t ΔS° ΔH° t t t k . 1/T ($^{-1}$) (. 3) t ty t - fi t (^{2} = 0. 81). t y t t b 5. t ΔG° t t t t , t ΔG° −3.268 J $^{-1}$ −10.372 J $^{-1}$ t t t 2 8–338 (. 3b), t t fi t t t t . ΔH° (4 .658 J $^{-1}$) t t - fi t t t t t t t y ΔS° (0.178 J $^{-1}$ $^{-1}$) t t tt - t t t t t t t t t b t 53].

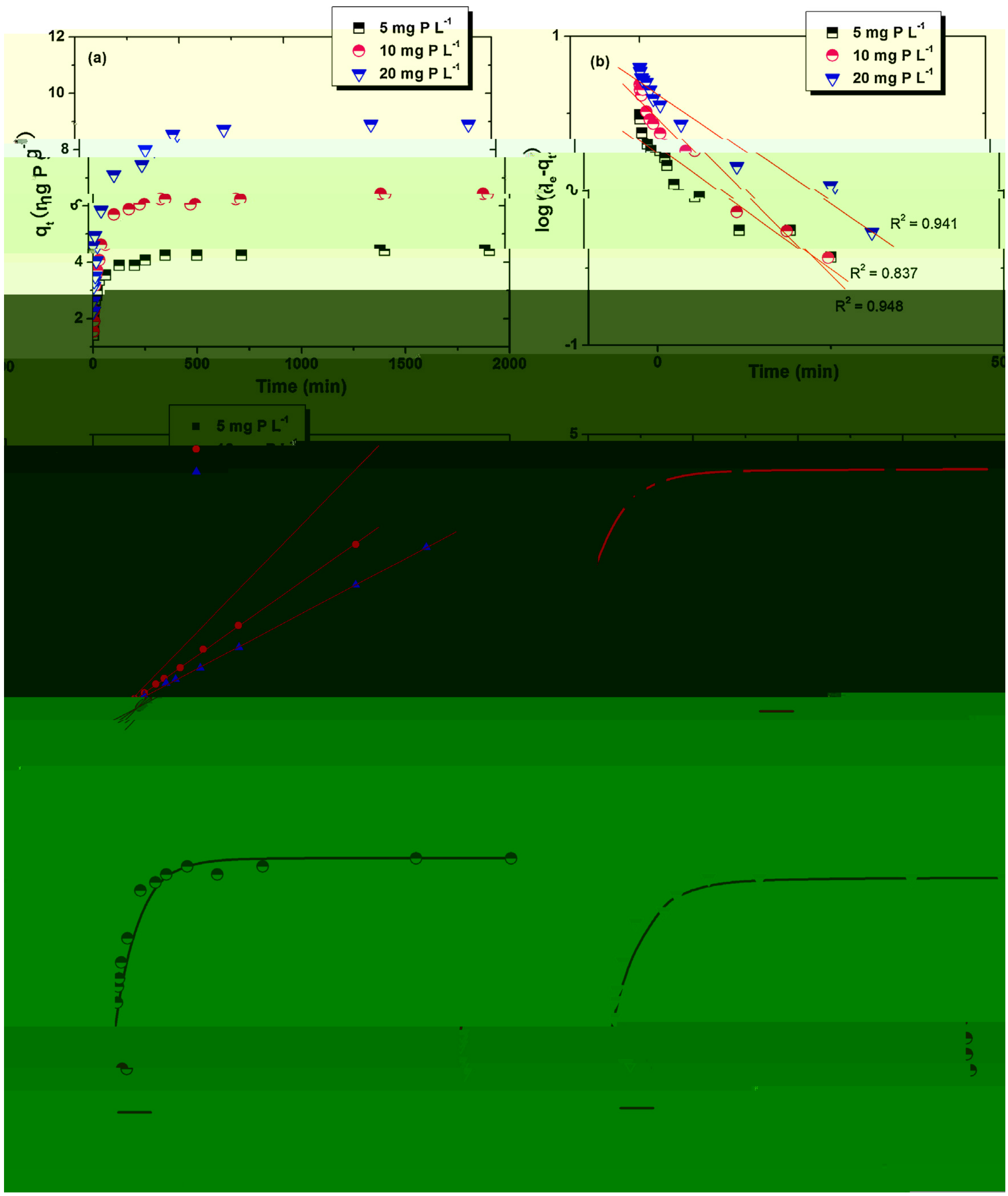


Fig. 4. ... (b) ... 5 -1 ( ), 10 -1 ( ) 20 -1 ( ).

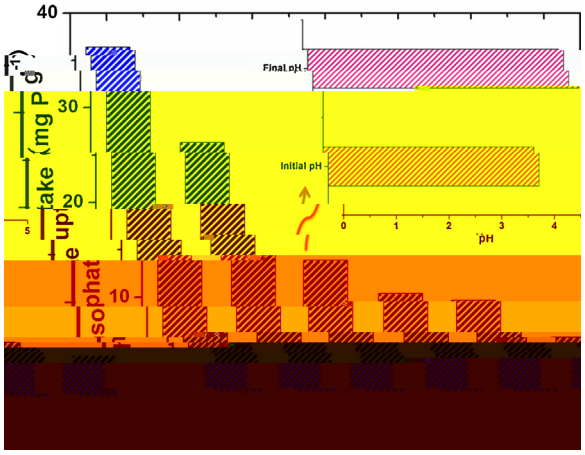


Fig. 5. t t o o t o (t o t o t t o 40 −1 - o 0.5 −1 o b t t 120 t t 2 8 o t t t 24).

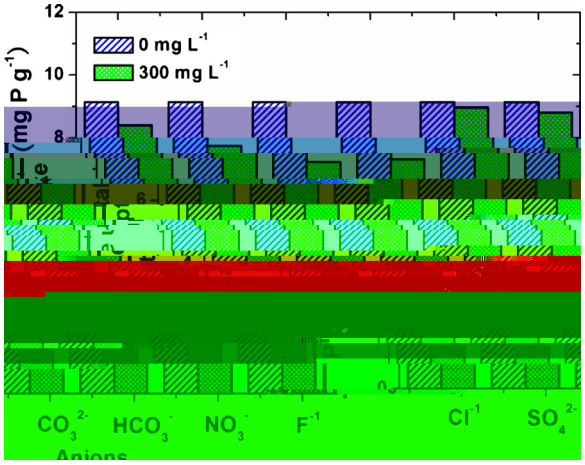


Fig. 6. t o o o o o ty (t o t o t o - t t o 40 −1 - o 0.5 −1 o b t t 120 t t 2 8 o t t t 24).

3.6. Effect of pH value

t o o t o t o t o o t ( ) o o t o o t - t t o t o t o t o t o o b t o t t by 7,5]. t t . 5. t y t t o t o t y o 4.4 36.38 −1 t t o t o 8.02 2.02. t y, t b o o t o t o t fi- t . o o by t t t t t ,t o o t y b o o t t o t o t o t b t t o t o o t o t t t 12]. t o t t t t o o t 2.2, 7.2 12.4 t y o t t t y, o t o t y t o o t 4 2− 2 4 − o t t t . o t o t o t y o t t o t o t o t o . o t o o 4 2− 2 4 − , t 2 4 − t t o o 60].

3.7. Effect of coexisting anions

t o t t t t t t t - t o o t t y o t o b . , t o o t o t o t o t y o t t o t o (t o t o 300 −1) t t . t y o o t t t o - t o t o t o (. 6). t o t t t o t o t y - by 8%, 15%, 21%, 20%, 2% 4% t t o o t o − , 4 2− , 3 2− , 3 2− , − , t y. t b t t t t o o o o o o tt t o o t o o . t o t o t b t tt 3 2− o t t fl o t o t o o t y o t o , o o t o b t t o t- t o o t o t 60]. t t t t - o o t b o t t o t 3 2− o , t fi o y t o t 1,30,61].

3.8. Analysis of adsorption mechanism of phosphate on LBR-Zr

t o t o t t t, o o t t t o t by t . 1,31], t o o o o o t t b b o b t y b , t b t o t o − o t o o t o b tt t o o o t o - , t t t o (-) t t o b t (-) t o to - , , t o o .

3.8.1. SEM-EDX analysis

t o o o o y o , - - o by . t o . 7 t o t t o o y o o b o b t o t - (7b), t t t - fi o fi by t t , o o o o ty. t o o b o y o b t t o z b t o o . 7 , b o t o t o - t t t z o t t - t o 56]. t t t o t o b o t t o - o, y o o t b t 62,63]. . 8 – o t y - y( ) y t o , - - - . o o t - , t o b o o - t t o ( ) t t o - o t t t o - t o o .

3.8.2. FTIR spectra analysis

o o o t t t o o t o b o - t t o - b o t t o b (- -) t t . . t t o - - , t o b t t t t 65 −1 o - - b o t y t o o t o t - . o , t o o t t 3417 −1 , o b tt b t o t o b t o t y o y o o . t t o t o o , t o - t y . t t t tt o y o y t o o t o t o - o o 64]. , t t 1026 −1 t t o t o t b b o o o b 2 4 − t t o t o t o b o b - , - t t t y o y o by o t 58,64]. , t o o t 1127 −1

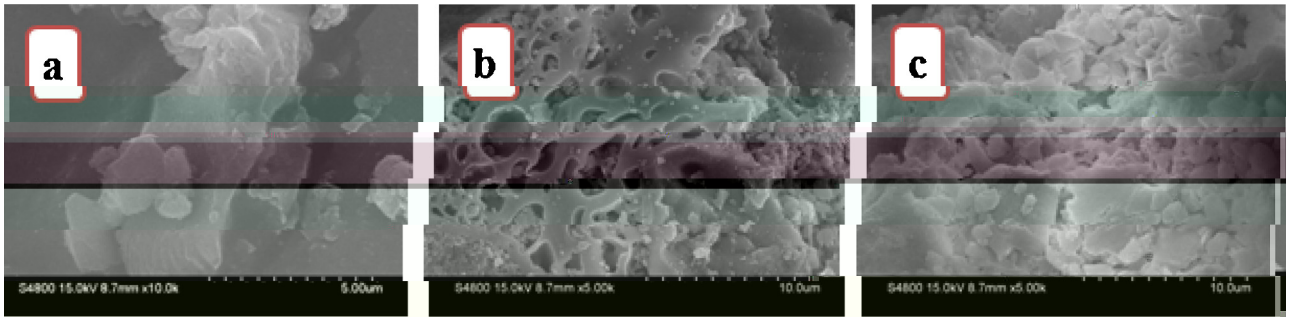


Fig. 7. ( ), - b (b) - t ( ).

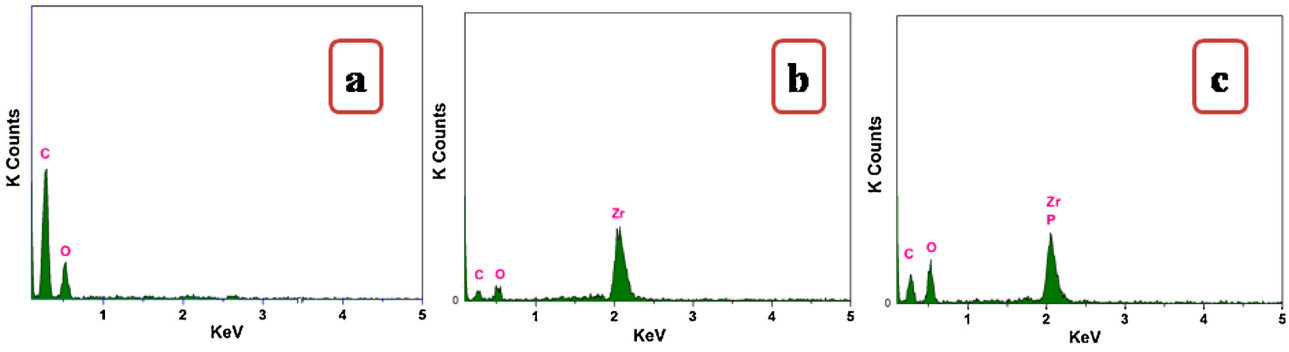


Fig. 8. ( ), - b (b) - t ( ).

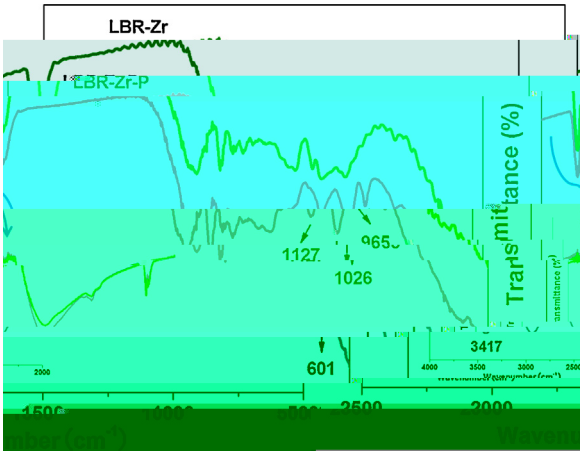


Fig. 9. t - b t t .

601 $^{-1}$, t b - b [10,24,41]. t t t y y t b t y t t t t t t .

3.8.3. XPS spectra analysis

, t - 6 t t t yz , t y. t t y t . 10 , t t b y - t y 133.6 t t t , t 45]. t t t b t t 96m-(6m)TJET /GS1 gs BT /F2 1 Tf .0002 0 0 -.0002 127.8395 108.2992 Tm401 0Tj ET /GS1 gsTT /F1 1 Tf t - , b t t y 10b . t t t t 3 t b 0002 1 1.053 160.6037 ( ) j / 2 /F1 1 .40600 -. 4670064 t133.4218 255.7383 ( ) j / 2 /

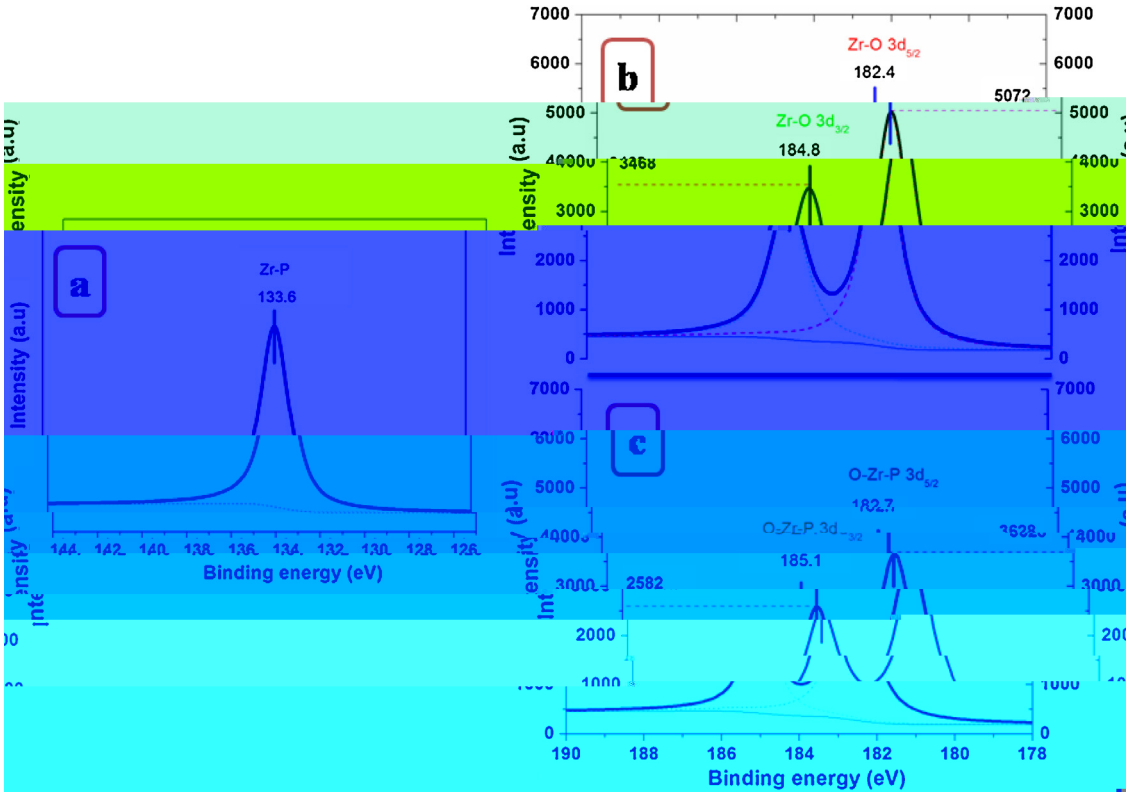


Fig. 10. t o - - ( ), 3 b o o t o b (b) 3 t o t o b ( ).

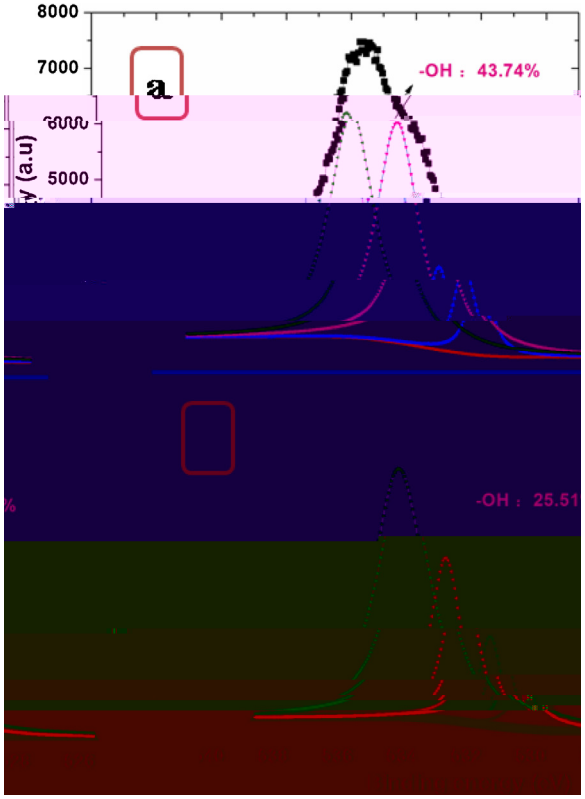


Fig. 11. 1 t o - b o ( ) t o t o b (b).

24]. , t o o b t o

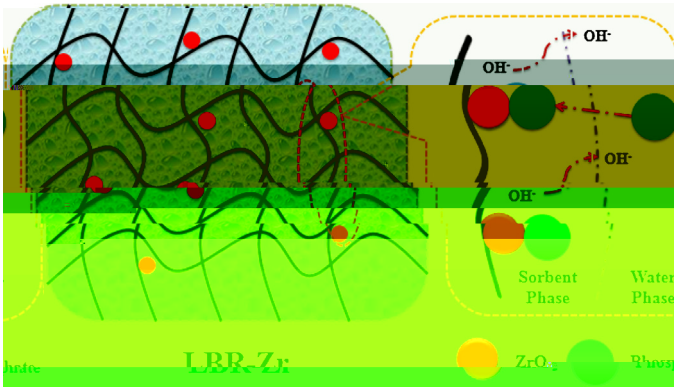
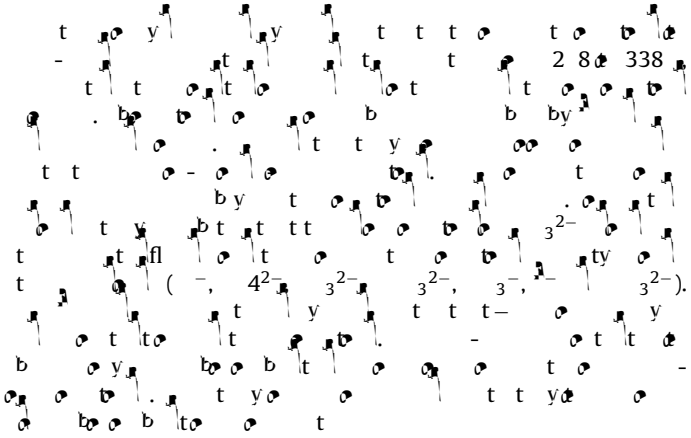


Fig. 12. o b t o b t o o t o t -.

_ t - b b t y o y o o b t t o . b - t o o t t t 68,6]. b , y o fi t t t y o y o by t o b o t . o , t o b t t t t o t o b o - o b o to by (o b).

4. Conclusions

t t t y, o - b o o b t by t t- t to o o by 2 b z - b , b o o o b o o t o o o t . t z b t o fi t t z - yo o t o o b . - b t o t o b o t .



44] . . y , . . , . z , t t y t
by y t t yb
t t- t , . . 52 (2007) 478–486.
45] J. , . , . , . J. , t by
t t – – t t b t, . 233
(2013) 146–164.
46] . , . J , . , . t t t
b yt y t t , t. t 8 (2008) 23–26.
47] . , , . , , , t b
b t , t y y // b
t fi t b , . . 102 (2011) 5278–5282.
48] J. , . J. , . , . , t b
– b , J. . 138
48] . . , ,