白菜渣对重金属离子铜的吸附研究

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摘 要:采用二次回归正交旋转组合设计,研究白菜渣对重金属铜离子的吸附作用;建立了吸附率对铜离子浓度、白菜渣加入量、溶液 pH、吸附温度及吸附时间 5 个试验因素的正交回归模型。结果表明:Cu^{2+} 浓度 50 mg/L、菜渣量 0.5 g、pH 6、温度 20℃、时间 4 h 时,吸附率达最大值 Y_{max}=98.11%。回归模型经显著性检验达显著水平,较好拟合了吸附率与各因子之间的关系。

关键词:白菜渣;Cu^{2+};吸附;二次回归正交旋转组合设计

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重金属污染问题日趋严重,尤其是水体重金属污染。由于重金属具有毒性强、毒性长和生物富集性的特点,严重危害着人类及各类水生生物的生存和水资源的有效利用。传统的治理重金属污染的方法不仅价格昂贵,且存在有害副产品。有研究表明,膳食纤维中的酸性多糖有着很好的离子交换作用,特别是对重金属元素有很强的吸附作用[1]。寻求有效、经济、环保的生物吸附剂、探讨其最佳的吸附条件、吸附机理及吸附动力学,对治理重金属污染、保护环境具有积极意义。白菜中膳食纤维含量高,且白菜产量大、废弃量也大。研究白菜渣对常见有毒环境污染物之一的铜离子的吸附作用,对扩大白菜资源的利用、治理重金属污染和废弃白菜污染,具有广阔的应用前景。

1 材料与方法

1.1 试验材料

将市场购买的大白菜清洗→切碎→沸水煮 3~5 min→蒸馏水清洗 2 遍→榨汁→取渣→蒸馏水清洗 2 遍→过滤→碱液(pH 12 的氢氧化钠溶液)中 60℃恒温浸泡 2 h→蒸馏水漂洗至中性,过滤挤干→酸液(pH 2的盐酸溶液)中 60℃恒温浸泡 2 h→蒸馏水漂洗至中性,过滤挤干→恒温干燥箱中 60℃干燥 24 h→粉碎,过 60 目筛→干燥器中备用[2]。

1.2 试验方法

在各试管中分别加入不同浓度硫酸铜溶液 50 mL,再分别加入不同量的白菜纤维素渣,分别置于不同条件下,密封静置吸附不同的时间后过滤,取上清液用原子吸收分光光度计测量吸光度,利用标准曲线计算滤液中铜离子浓度,最终计算出相应的吸附率。吸附率=(Co-C)×100%/C,其中:Co 为 Cu^{2+} 离子的初始浓度(mg/L),C 为经菜渣吸附后的平衡浓度(mg/L)。

1.3 试验设计

采用二次回归正交旋转组合设计,对影响吸附的主要因素 Cu^{2+} 浓度、白菜渣加入量、pH、吸附温度、吸附时间进行优化[3]。五因素五水平共 36 个处理,3 次重复,以结果的平均数参加回归运算,因子水平设置及编码见表 1。

表 1 因素水平编码

Table 1 Factors and levels of the test

编码水平 Code level	X_1 Cu^{2+}浓度 Cu^{2+} concentration /mg·L^{-1}	X_2 菜渣量 Dish slag quantity /g	X_3 pH	X_4 温度 Temperature /℃	X_5 时间 Time /h
2	50	0.9	10	60	6
1	40	0.7	8	50	5
0	30	0.5	6	40	4
-1	20	0.3	4	30	3
-2	10	0.1	2	20	2

2 结果与分析

2.1 硫酸铜溶液标准曲线绘制

Cu^{2+} 离子(mg/L)标准曲线见图 1。

2.2 正交实验结果

由表 2 可知,Cu^{2+} 浓度、菜渣量、pH、温度、时间对吸附率 Y(%)正交旋转组合设计的 36 个组合中,

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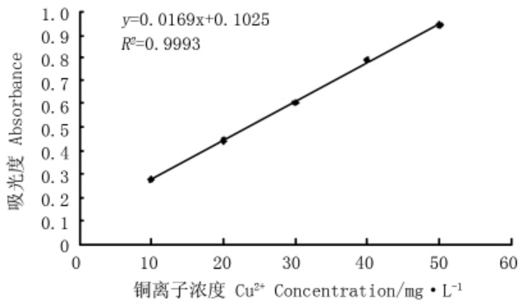

图 1　硫酸铜溶液标准曲线

Fig. 1　Cu^{2+} standard curve

组合 36 的吸附率最高，为 90.828%，此时 Cu^{2+} 浓度为 30 mg/L，菜渣量 0.5 g，pH 6，温度 40℃，时间 4 h。

2.3　吸附率二次回归模型的组建与检验

利用 DPS 数据处理系统建立对 Cu^{2+} 吸附率的二次回归模型并进行检验，结果见表 3。回归方程：$Y=85.03691+11.82816X_1-6.82322X_2+0.22806X_3+2.15935X_4+0.97592X_5-4.84827X_1^2-2.60468X_2^2-2.30882X_3^2-1.61849X_4^2-3.64018X_5^2+3.92936X_1X_2+0.37907X_1X_3-3.28217X_1X_4-0.47152X_1X_5-0.41605X_2X_3+0.65643X_2X_4+0.02774X_2X_5-0.15717X_3X_4-1.30362X_3X_5+1.02626X_4X_5$。

表 2　试验设计组合及结果

Table 2　Five factor orthogonal return rotatable design combination and results

代号 No.	X_1	X_2	X_3	X_4	X_5	Y/%
1	1	1	1	1	1	78.032544
2	1	1	1	−1	−1	84.689349
3	1	1	−1	1	−1	80.547337
4	1	1	−1	−1	1	79.807692
5	1	−1	1	1	−1	87.056213
6	1	−1	1	−1	1	84.245562
7	1	−1	−1	1	1	85.133136
8	1	−1	−1	−1	−1	88.683432
9	−1	1	1	1	−1	54.289941
10	−1	1	1	−1	1	37.721893
11	−1	1	−1	1	1	57.544379
12	−1	1	−1	−1	−1	43.343195
13	−1	−1	1	1	1	72.928994
14	−1	−1	1	−1	−1	67.307692
15	−1	−1	−1	1	−1	73.52071
16	−1	−1	−1	−1	1	64.053254
17	−2	0	0	0	0	41.715976
18	2	0	0	0	0	84.911243
19	0	−2	0	0	0	86.489152
20	0	2	0	0	0	58.086785
21	0	0	−2	0	0	70.512821
22	0	0	2	0	0	76.42998
23	0	0	0	−2	0	73.076923
24	0	0	0	2	0	79.38856
25	0	0	0	0	−2	57.29783
26	0	0	0	0	2	78.994083
27	0	0	0	0	0	87.869822
28	0	0	0	0	0	89.053254
29	0	0	0	0	0	81.952663
30	0	0	0	0	0	78.205128
31	0	0	0	0	0	83.925049
32	0	0	0	0	0	86.291913
33	0	0	0	0	0	83.333333
34	0	0	0	0	0	86.094675
35	0	0	0	0	0	87.475345
36	0	0	0	0	0	90.828402

由表 3 可知，X_1、X_2、X_1^2、X_5^2 达极显著水平，X_2^2、X_3^2、X_1X_2、X_1X_4 达显著水平，X_4 有一定的显著性。$F_{失拟}=4.24257<F_{0.01}(6,9)=5.80$，表明未知因素对试验结果影响小，可以忽略；$F_{回归}=10.60364>F_{0.05}(20,15)=2.33$，达到显著水平，说明回归模型成立，以此模型进行预报具有较高的可行性。回归方程拟合很好，可剔除不显著项，构成简化回归方程（$\alpha=0.10$）：$Y=85.03691+11.82816X_1-6.82322X_2+2.15935X_4-4.84827X_1^2-2.60468X_2^2-2.30882X_3^2-3.64018X_5^2+3.92936X_1X_2-3.28217X_1X_4$。

表 3 回归关系方差分析

Table 3 A regressive relation analysis of variance table

变异来源 Source of variation	平方和 Square sum	自由度 Freedom	均方 Mean square	比值 F Ratio	显著水平 P Significant level
X_1	3 357.726	1	3 357.726	105.6788**	0.0001
X_2	1 117.354	1	1 117.354	35.1668**	0.0001
X_3	1.2482	1	1.2482	0.0393	0.8455
X_4	111.9073	1	111.9073	3.5221△	0.0801
X_5	22.8581	1	22.8581	0.7194	0.4097
X_1^2	752.1831	1	752.1831	23.6737**	0.0002
X_2^2	217.0995	1	217.0995	6.8328*	0.0195
X_3^2	170.5811	1	170.5811	5.3688*	0.035
X_4^2	83.824	1	83.824	2.6382	0.1251
X_5^2	424.0299	1	424.0299	13.3456**	0.0024
X_1X_2	247.0384	1	247.0384	7.7751*	0.0138
X_1X_3	2.2991	1	2.2991	0.0724	0.7916
X_1X_4	172.3627	1	172.3627	5.4248*	0.0342
X_1X_5	3.5574	1	3.5574	0.112	0.7426
X_2X_3	2.7696	1	2.7696	0.0872	0.7719
X_2X_4	6.8945	1	6.8945	0.217	0.648
X_2X_5	0.0123	1	0.0123	0.0004	0.9846
X_3X_4	0.3953	1	0.3953	0.0124	0.9127
X_3X_5	27.191	1	27.191	0.8558	0.3696
X_4X_5	16.8513	1	16.8513	0.5304	0.4777
回归	6 738.183	20	336.9091	F_2=10.60364	0.0001
剩余	476.5943	15	31.773		
失拟	352.1045	6	58.6841	F_1=4.24257	0.0108
误差	124.4899	9	13.8322		
总和	7 214.777	35			

2.3 优化分析

用DPS软件中的数据优化程序求得Y_{max}时，5个因素水平取在(2、0、0、－2、0)。即铜离子浓度为50 mg/L、菜渣量0.5 g、pH 6、温度20℃、时间4 h时，吸附率最大，Y_{max}＝98.11％。

2.4 单因子效应分析(其它因子取零水平)

由表4可知，在试验范围内，对吸附率影响最大的是Cu^{2+}浓度，在浓度为40 mg/L时达到最大值92.017％；其次是白菜渣加入量，在加入量为0.2 g时吸附率达最大值89.411％；温度有一定影响性，60℃吸附率达最大值89.356％；时间和pH影响不大，pH 6和时间4 h吸附率好，为85.037％。

表 4 单因子效应分析

Table 4 Effect analysis of single factor

水平 Level	X_1	X_2	X_3	X_4	X_5
－2	41.988	88.265	75.802	80.718	70.476
－1.5	56.386	89.411	79.842	81.798	76.847
－1	68.36	89.255	82.728	82.878	81.397
－0.5	77.911	87.797	84.46	83.957	84.127
0	85.037	85.037	85.037	85.037	85.037
0.5	89.739	80.974	84.46	86.117	84.127
1	92.017	75.609	82.728	87.196	81.397
1.5	91.871	68.942	79.842	88.276	76.847
2	89.3	60.972	75.802	89.356	70.476

2.5 双因子互作效应分析(其它因子为零水平)

由表5可知，浓度40 mg/L、菜渣量0.4 g时，吸附率有大值92.8126％；浓度10 mg/L、菜渣量0.9 g时，吸附率有小值2.2049％。由表6可知，浓度40 mg/L、pH 6时，吸附率有大值为92.0168％；浓度10 mg/L、pH 2或pH 10时，吸附率有小值32.7522％。由表7可知，浓度50 mg/L、温度20℃时，吸附率有大值98.1101％；浓度10 mg/L、温度20℃时，吸附率有小值24.5401％。由表8可知，浓度40 mg/L、时间4 h时，吸附率有大值92.0168％；浓度10 mg/L、时间2 h或6 h时，吸附率有小值27.4268％。由表9可知，菜渣量0.2 g、pH 6时，吸附率有大值89.4112％；菜渣量0.9 g、pH 2或pH 10时，吸附率有小值51.7365％。由表10可知，菜渣量0.3 g、温度为60℃时，吸附率有

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大值 93.5742%;菜渣量 0.9 g,温度 20℃时,吸附率有小值 56.653%。由表 11 可知,菜渣量 0.2 g、时间 4 h 时,吸附率有大值 89.4112 %;菜渣量 0.9 g、时间 2 h 或 6 h 时,吸附率有小值 46.411%。由表 12 可知,pH 6、温度 60℃时,吸附率有大值 89.3556%;在pH 2,温度 20℃时,吸附率有小值 71.4829%。由表 13 可知,pH 6、时间 4 h 时,吸附率有大值 85.0369%;pH 10 或 pH 2、时间 2 h 或 6 h 时,吸附率有小值 61.2409%。由表 14 可知,温度 60℃、时间 4 h 时,吸附率有大值 89.3556%;温度 20℃,时间 6 h 或 2 h 时,吸附率有小值 66.1575%。

表 5 浓度与菜渣量对吸附率的影响

Table 5 The influence of concentration and joins the quantity on the adsorbs rate %

水平 Level X_1X_2	−2	−1.5	−1	−0.5	0	0.5	1	1.5	2
2	76.814	81.884	85.66	88.132	89.301	89.167	87.731	84.999	80.954
1.5	83.312	87.408	90.195	91.684	91.875	90.758	88.337	84.612	79.595
1	87.3858	90.4971	92.306	92.8126	92.0168	89.9187	86.5183	81.8155	75.8104
0.5	89.0373	91.1662	91.9928	91.517	89.7389	86.6585	82.2757	76.5906	69.6031
0	88.2646	89.4112	89.2555	87.7974	85.0369	80.9741	75.609	68.9415	60.9717
−0.5	85.0679	85.2321	84.094	81.6536	77.9108	72.8656	66.5182	58.8684	49.9162
−1	79.4469	78.6288	76.5084	73.0856	68.3605	62.333	55.0032	46.3711	36.4366
−1.5	71.4019	69.6014	66.4987	62.0935	56.3861	49.3763	41.0641	31.4496	20.5328
−2	60.9327	58.1499	54.0648	48.6773	41.9875	33.9954	24.7009	14.1041	2.2049

表 6 浓度与 pH 对吸附率的影响

Table 6 The influence of concentration and the pH on the adsorbs rate %

水平 Level X_1X_3	−2	−1.5	−1	−0.5	0	0.5	1	1.5	2
2	80.0649	84.1053	86.9913	88.7229	89.3001	88.7229	86.9913	84.1053	80.0649
1.5	82.6353	86.6757	89.5617	91.2933	91.8705	91.2933	89.5617	86.6757	82.6353
1	82.7815	86.8219	89.708	91.4396	92.0168	91.4396	89.708	86.8219	82.7815
0.5	80.5036	84.5441	87.4301	89.1617	89.7389	89.1617	87.4301	84.5441	80.5036
0	75.8016	79.8421	82.7281	84.4597	85.0369	84.4597	82.7281	79.8421	75.8016
−0.5	68.6755	72.7159	75.6019	77.3336	77.9108	77.3336	75.6019	72.7159	68.6755
−1	59.1252	63.1656	66.0517	67.7833	68.3605	67.7833	66.0517	63.1656	59.1252
−1.5	47.1508	51.1912	54.0773	55.8089	56.3861	55.8089	54.0773	51.1912	47.1508
−2	32.7522	36.7927	39.6787	41.4103	41.9875	41.4103	39.6787	36.7927	32.7522

表 7 浓度与温度对吸附率的影响

Table 7 The influence of concentration and temperature on the adsorbs rate %

水平 Level X_1X_4	−2	−1.5	−1	−0.5	0	0.5	1	1.5	2
2	98.1101	95.9076	93.7051	91.5026	89.3001	87.0976	84.8951	82.6927	80.4902
1.5	97.3984	96.0164	94.6344	93.2525	91.8705	90.4886	89.1066	87.7247	86.3427
1	94.2624	93.701	93.1396	92.5782	92.0168	91.4554	90.894	90.3326	89.7712
0.5	88.7024	88.9615	89.2207	89.4798	89.7389	89.9981	90.2572	90.5163	90.7755
0	80.7182	81.7979	82.8776	83.9572	85.0369	86.1166	87.1963	88.2759	89.3556
−0.5	70.3099	72.2101	74.1103	76.0105	77.9108	79.811	81.7112	83.6114	85.5116
−1	57.4774	60.1982	62.919	65.6397	68.3605	71.0813	73.802	76.5228	79.2435
−1.5	42.2208	45.7622	49.3035	52.8448	56.3861	59.9274	63.4687	67.01	70.5513
−2	24.5401	28.902	33.2638	37.6257	41.9875	46.3494	50.7112	55.0731	59.4349

表 8 浓度与时间对吸附率的影响

Table 8 The influence of concentration and the time on the adsorbs rate %

水平 Level X_1X_5	−2	−1.5	−1	−0.5	0	0.5	1	1.5	2
2	74.7394	81.1097	85.66	88.3901	89.3001	88.3901	85.66	81.1097	74.7394
1.5	77.3098	83.6801	88.2304	90.9605	91.8705	90.9605	88.2304	83.6801	77.3098
1	77.4561	83.8264	88.3766	91.1068	92.0168	91.1068	88.3766	83.8264	77.4561
0.5	75.1782	81.5485	86.0987	88.8289	89.7389	88.8289	86.0987	81.5485	75.1782
0	70.4762	76.8465	81.3967	84.1269	85.0369	84.1269	81.3967	76.8465	70.4762
−0.5	63.35	69.7204	74.2706	77.0007	77.9108	77.0007	74.2706	69.7204	63.35
−1	53.7998	60.1701	64.7203	67.4504	68.3605	67.4504	64.7203	60.1701	53.7998
−1.5	41.8253	48.1957	52.7459	55.476	56.3861	55.476	52.7459	48.1957	41.8253
−2	27.4268	33.7971	38.3473	41.0775	41.9875	41.0775	38.3473	33.7971	27.4268

表 9　　菜渣量与 pH 对吸附率的影响

Table 9　　The influence of joins the quantity with pH on the adsorbs rate　　%

水平 Level X_2X_3	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2
2	51.7365	55.7769	58.6629	60.3945	60.9717	60.3945	58.6629	55.7769	51.7365
1.5	59.7063	63.7467	66.6327	68.3643	68.9415	68.3643	66.6327	63.7467	59.7063
1	66.3737	70.4142	73.3002	75.0318	75.609	75.0318	73.3002	70.4142	66.3737
0.5	71.7388	75.7793	78.6653	80.3969	80.9741	80.3969	78.6653	75.7793	71.7388
0	75.8016	79.8421	82.7281	84.4597	85.0369	84.4597	82.7281	79.8421	75.8016
-0.5	78.5621	82.6025	85.4885	87.2202	87.7974	87.2202	85.4885	82.6025	78.5621
-1	80.0202	84.0606	86.9466	88.6783	89.2555	88.6783	86.9466	84.0606	80.0202
-1.5	80.1759	84.2164	87.1024	88.834	89.4112	88.834	87.1024	84.2164	80.1759
-2	79.0294	83.0698	85.9558	87.6874	88.2646	87.6874	85.9558	83.0698	79.0294

表 10　　菜渣量与温度对吸附率的影响

Table 10　　The influence of joins the quantity and the temperature to adsorbs rate　　%

水平 Level X_2X_4	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2
2	56.653	57.7327	58.8124	59.8921	60.9717	62.0514	63.1311	64.2108	65.2904
1.5	64.6228	65.7025	66.7822	67.8619	68.9415	70.0212	71.1009	72.1806	73.2603
1	71.2903	72.37	73.4497	74.5293	75.609	76.6887	77.7684	78.848	79.9277
0.5	76.6554	77.7351	78.8148	79.8945	80.9741	82.0538	83.1335	84.2132	85.2928
0	80.7182	81.7979	82.8776	83.9572	85.0369	86.1166	87.1963	88.2759	89.3556
-0.5	83.4787	84.5583	85.638	86.7177	87.7974	88.877	89.9567	91.0364	92.1161
-1	84.9368	86.0164	87.0961	88.1758	89.2555	90.3351	91.4148	92.4945	93.5742
-1.5	85.0925	86.1722	87.2519	88.3315	89.4112	90.4909	91.5706	92.6502	93.7299
-2	83.9459	85.0256	86.1053	87.185	88.2646	89.3443	90.424	91.5037	92.5833

表 11　　菜渣量与时间对吸附率的影响

Table 11　　The influence of joins the quantity and the time on the adsorbs rate　　%

水平 Level X_2X_5	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2
2	46.411	52.7813	57.3316	60.0617	60.9717	60.0617	57.3316	52.7813	46.411
1.5	54.3808	60.7511	65.3014	68.0315	68.9415	68.0315	65.3014	60.7511	54.3808
1	61.0483	67.4186	71.9688	74.699	75.609	74.699	71.9688	67.4186	61.0483
0.5	66.4134	72.7837	77.3339	80.0641	80.9741	80.0641	77.3339	72.7837	66.4134
0	70.4762	76.8465	81.3967	84.1269	85.0369	84.1269	81.3967	76.8465	70.4762
-0.5	73.2366	79.6069	84.1572	86.8873	87.7974	86.8873	84.1572	79.6069	73.2366
-1	74.6947	81.065	85.6153	88.3454	89.2555	88.3454	85.6153	81.065	74.6947
-1.5	74.8505	81.2208	85.771	88.5012	89.4112	88.5012	85.771	81.2208	74.8505
-2	73.7039	80.0742	84.6245	87.3546	88.2646	87.3546	84.6245	80.0742	73.7039

表 12　　pH 与温度对吸附率的影响

Table 12　　The influence of pH and the temperature on the adsorbs rate　　%

水平 Level X_3X_4	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2
2	71.4829	72.5626	73.6423	74.7219	75.8016	76.8813	77.961	79.0407	80.1203
1.5	75.5234	76.603	77.6827	78.7624	79.8421	80.9217	82.0014	83.0811	84.1608
1	78.4094	79.4891	80.5687	81.6484	82.7281	83.8078	84.8874	85.9671	87.0468
0.5	80.141	81.2207	82.3004	83.38	84.4597	85.5394	86.6191	87.6987	88.7784
0	80.7182	81.7979	82.8776	83.9572	85.0369	86.1166	87.1963	88.2759	89.3556
-0.5	80.141	81.2207	82.3004	83.38	84.4597	85.5394	86.6191	87.6987	88.7784
-1	78.4094	79.4891	80.5687	81.6484	82.7281	83.8078	84.8874	85.9671	87.0468
-1.5	75.5234	76.603	77.6827	78.7624	79.8421	80.9217	82.0014	83.0811	84.1608
-2	71.4829	72.5626	73.6423	74.7219	75.8016	76.8813	77.961	79.0407	80.1203

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表 13 pH 与时间对吸附效率的影响

Table 13 The influence of pH and the time on the adsorbs rate %

水平 Level X_3 X_5	−2	−1.5	−1	−0.5	0	0.5	1	1.5	2
2	61.2409	67.6112	72.1614	74.8916	75.8016	74.8916	72.1614	67.6112	61.2409
1.5	65.2813	71.6517	76.2019	78.932	79.8421	78.932	76.2019	71.6517	65.2813
1	68.1674	74.5377	79.0879	81.818	82.7281	81.818	79.0879	74.5377	68.1674
0.5	69.899	76.2693	80.8195	83.5497	84.4597	83.5497	80.8195	76.2693	69.899
0	70.4762	76.8465	81.3967	84.1269	85.0369	84.1269	81.3967	76.8465	70.4762
−0.5	69.899	76.2693	80.8195	83.5497	84.4597	83.5497	80.8195	76.2693	69.899
−1	68.1674	74.5377	79.0879	81.818	82.7281	81.818	79.0879	74.5377	68.1674
−1.5	65.2813	71.6517	76.2019	78.932	79.8421	78.932	76.2019	71.6517	65.2813
−2	61.2409	67.6112	72.1614	74.8916	75.8016	74.8916	72.1614	67.6112	61.2409

表 14 温度与时间对吸附率的影响

Table 14 The influence of temperature and the time on the adsorbs rate %

水平 Level X_4 X_5	−2	−1.5	−1	−0.5	0	0.5	1	1.5	2
2	74.7949	81.1652	85.7154	88.4456	89.3556	88.4456	85.7154	81.1652	74.7949
1.5	73.7152	80.0855	84.6358	87.3659	88.2759	87.3659	84.6358	80.0855	73.7152
1	72.6355	79.0059	83.5561	86.2862	87.1963	86.2862	83.5561	79.0059	72.6355
0.5	71.5559	77.9262	82.4764	85.2065	86.1166	85.2065	82.4764	77.9262	71.5559
0	70.4762	76.8465	81.3967	84.1269	85.0369	84.1269	81.3967	76.8465	70.4762
−0.5	69.3965	75.7668	80.3171	83.0472	83.9572	83.0472	80.3171	75.7668	69.3965
−1	68.3168	74.6871	79.2374	81.9675	82.8776	81.9675	79.2374	74.6871	68.3168
−1.5	67.2372	73.6075	78.1577	80.8878	81.7979	80.8878	78.1577	73.6075	67.2372
−2	66.1575	72.5278	77.078	79.8082	80.7182	79.8082	77.078	72.5278	66.1575

3 结论

在试验设计的 5 个因素中，对吸附率影响最大的是 Cu^{2+} 浓度，其次是白菜渣加入量、温度有一定影响性，时间和 pH 影响性不大。双因子交互作用对吸附率影响较大的依次是 Cu^{2+} 浓度和菜渣量、Cu^{2+} 浓度和温度、Cu^{2+} 浓度和时间、Cu^{2+} 浓度和 pH。其余双因子交互作用对吸附率也有一定影响。在铜离子浓度 50 mg/L，菜渣量 0.5 g，pH 6，温度 20℃，时间 4 h 时，有最大吸附率 Y_{max}＝98.11%。

参考文献

[1] 潘海燕，冀兰涛，丁清波. 落叶对重金属吸附的初步研究[J]. 环境与发展，2001，16(2)：30-31.

[2] 曹树稳，黄绍华. 几种膳食纤维的制备工艺研究[J]. 食品科学，1997(6)：41-45.

[3] 朱彩平，曹慧. 应用二次回归旋转正交组合设计提取平菇多糖的工艺研究[J]. 中药材，2010(9)：1490-1494.

Study on the Brass Adsorption of Heavy Metal Ions in Cabbage Slag

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Abstract：The effects of adsorption of cabbage slag on heavy metal ions of brass were studied with the method of thequadratic regression orthogonal rotating combination design. The regression model of adsorption rate was established on copper ion concentration combination，dish slag quantity，pH，temperature，time. The results showed that the of model to infer showed that cabbage residue on adsorption of Cu^{2+} in the best condition to reach the largest adsorption rate Y_{max}＝98.11% was at a concentration of 50 mg/L，addition of 0.5 g，pH 6，temperature of 20℃，time of 4 h. The regression model established by significant test ascended a significant level，model analyses factors adsorption rate and the relationship between them.

Key words：cabbage slag；Cu^{2+}；adsorption；quadratic orthogonal rotation；combination design