

# Research on the Oxidation of Chrome (III) to Chrome (VI) by Hydroxyl Radical

*Ling Zhang<sup>1,2</sup>, Congzheng Yu<sup>1,\*</sup>, Hongmin Yang<sup>1</sup>, Qiang Hu<sup>1</sup>*

<sup>1</sup> College of Resources and Environment, Shaanxi University of Science & Technology, Xi'an, Shaanxi, 710021, P. R. China

<sup>2</sup> PhD Candidate, School of Sciences, Nanchang University, Nanchang, Jiangxi, 330031, P. R. China

**Abstract:** By simulating the hydroxyl radical produced from the oxidation of lipoids in the leather fat liquoring agent, the oxidation of chrome (III) by hydroxyl radical, which was produced from Fenton reagent, was studied. The Fenton reagent contributed to the dissolution of chrome trichloride, chrome trichloride-benzoic acid and chrome tanning agent, respectively. At a certain time interval, the contents of chrome (VI) in each solution were determined. The effect of hydroxyl radical on the contents of chrome (VI) in leather was explored. And the influence of hydroxyl radical scavenger-benzoic acid on the production of chrome (VI) was studied. The results showed that the hydroxyl radical produced by the oxidation of leather fat liquoring agent could oxidize chrome (III) to chrome (VI) in the system of chrome trichloride. And the chrome (VI) contents in the system would increase with the concentration increasing of hydroxyl radical. However, the hydroxyl radical scavenger had the inhibitory action on the production of chrome (VI) in the system. The contents of chrome (VI) were decreasing by 99.3% when the amount of benzoic acid was 3% of the chrome mass and the reaction lasted for 90 min. And the chrome tanning agent had an inhibitory effect on the chrome (VI) formation.

**Key words:** chrome (VI); hydroxyl radical; Fenton reagent

## 1 Introduction

The finished leather contains trace  $\text{Cr}^{6+}$ , which has become a serious issue in leather industry. Researches indicated<sup>[1, 2]</sup> that fat liquoring has a heavy influence on formation of chromate in leather. The greatest effect is shown by the classical sulfated and sulfited fish oils and products with simple or multiple unsaturated fatty acids (free or esterified). Natural or synthetic fat liquoring agents without the above mentioned substances do not lead to chromate formation. The reasons why unsaturated fatty acids and their esters resulted in chromate formation are that these molecules all have double bonds whose vivid methylenes are easy to form free radical and produce hydroperoxide (ROOH). Then the hydroperoxide is easy to be decomposed into alkoxy radical ( $\text{RO}\cdot$ ) and hydroxyl radical ( $\cdot\text{OH}$ ). The hydroxyl radical is a very active but non-selective substance and has the strongest oxidability. Therefore, it is likely to become an oxidant for soluble  $\text{Cr}^{3+}$  in leather and oxidize  $\text{Cr}^{3+}$  to  $\text{Cr}^{6+}$ . Although the above-mentioned possibility

---

\* Corresponding author: Telephone: 13636738368, Email: yu46980@163.com

has not been proved yet, it might be one reason for the indirect production of  $\text{Cr}^{6+}$  in leather.

In this article, the way to get rid of the oils and fats in leather were studied by the traditional methods, and the method to remove the interference of the impurities on the experiment from the lipids oxidation was explored. It used the hydroxyl radical produced by Fenton reagents to simulate the resolution substance  $\bullet\text{OH}$  of a hydroperoxide produced by the lipids oxidation in leather. At the same time, in order to remove the interference of many factors in the tanning course, we used the hydroxyl radical produced by Fenton reagents to react with chrome trichloride and chrome powder tanning agent solution separately. It can be observed more directly and more effectively that  $\bullet\text{OH}$  produced from lipids oxidation has some effects on the soluble  $\text{Cr}^{3+}$  in leather.

## **2 Experimental Procedures**

### ***2.1 Instruments and materials***

721N Photoelectric spectrophotometer, Shanghai Third Analytical Instrument Plant; Ferrous sulfate, analytical purity, Shenyang Third Reagent Chemical Industry Plant; Chrome trichloride, analytical purity, Tianjin Fuchen Chemical Reagent Plant; Chrome powder tanning agent, industry purity, Langsheng Leather Chemical Industry Co., Ltd.; 30% hydrogen peroxide, analytical purity, Xi'an Chemical Reagent Plant; Benzoic acid, analytical purity, Tianjin Jinbei Refined Chemical Industry Co., Ltd..

### ***2.2 Experimental methods***

#### ***2.2.1 Chrome trichloride solution system***

(1)  $\text{CrCl}_3$ -Fenton solution system

Add 80 mL  $\text{CrCl}_3$  solution with 4g/L concentration (measured by  $\text{Cr}_2\text{O}_3$ ), 1.68 mL ferrous sulfate solution with 0.5 mol/L concentration, 1.30 mL  $\text{H}_2\text{O}_2$  solution with 3% concentration and 1.02mL distilled water into a 250mL conical flask. The mole ratio:  $n(\text{Cr}^{3+}) : n(\text{FeSO}_4) : n(\text{H}_2\text{O}_2) = 5 : 1 : 1.5$ . Put the conical flask on the magnetic stirrer to stir at the room temperature. Test the amounts of  $\text{Cr}^{6+}$  in the solution at the interval of certain time.

(2)  $\text{CrCl}_3$ -Fenton- Benzoic acid solution system

Add 80mL  $\text{CrCl}_3$  solution with 4g/L concentration (measured by  $\text{Cr}_2\text{O}_3$ ), 1.02mL benzoic acid solution (coming up to 1% chrome mass), 1.68 mL ferrous sulfate solution with 0.5mol/L concentration and 1.30 mL  $\text{H}_2\text{O}_2$  solution with 3% concentration into a 250mL conical flask. The mole ratio:  $n(\text{Cr}^{3+}) : n(\text{FeSO}_4) : n(\text{H}_2\text{O}_2) = 5 : 1 : 1.5$ . Put the conical flask on the magnetic stirrer to stir at the room temperature. Test the amounts of  $\text{Cr}^{6+}$  in the solution at the interval of certain time.

#### ***2.2.2 Chrome powder tanning agent solution system***

In chrome powder tanning agent-Fenton solution, the concentration of chrome powder tanning agent solution were both 0.4g/L (measured by  $\text{Cr}_2\text{O}_3$ ). The amount of other solutions and the experimental

procedures were the same as in 2.2.1(1).

### **2.2.3 Determination of Cr<sup>6+</sup>**

Spectrophotometric method was used to test Cr<sup>6+</sup> [3]. 15mL solution the above mentioned system was collected with a pipet and was washed twice with anhydrous ether. Then 10mL aqueous layer solution was sucked by a suction pipette and added to a 50mL volumetric flask, then 10 mL distilled water and 1mL 1:1 phosphoric acid were added successively. The mixed solution was well shaken up and 1mL 1, 5-diphenylcarbazide solution was added. Continue to shake the solution for 2min and the solution was laid quietly for 3min. Then 4mL p-methyl benzene sulfonic acid was added accurately and the solution was shaken up well. Then 10mL isoamyl alcohol was added accurately and the solution was shaken up again. After that, the solution was transferred to a separating funnel, laying and stratifying. 20min later, the water phase was leaked out and a small piece of absorbent cotton was stuffed into the neck of the funnel. Then the organic phase was filtrated, 3-4 drops per-minute. The contrast reagent was used as the parallel contrasting sample. Optical density of the organic phase was measured by a spectral photometer at 540nm in a 1cm color comparison container. The total content of Cr<sup>6+</sup> can be determined by comparing the optical density values and the calibration curve of the samples with corresponding known standard Cr (VI) concentration and their optical density values.

## **3 Results and discussion**

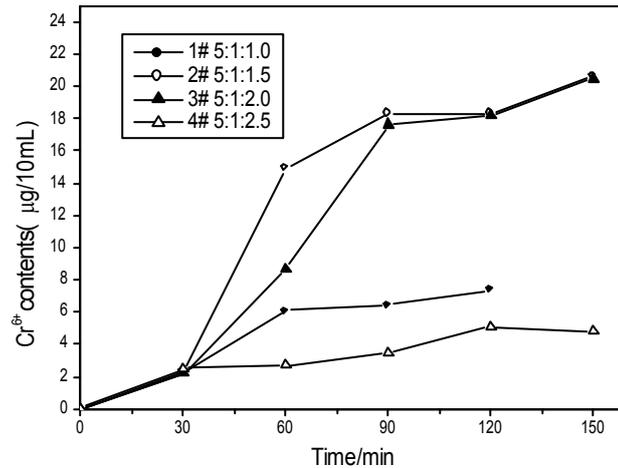
### **3.1 Oxidation of hydroxyl radical on Cr<sup>3+</sup> in chrome trichloride solution system.**

#### **3.1.1 Experimental results**

With the different mole ratios of Fenton reagents in CrCl<sub>3</sub> solution system, the variation of the amounts of Cr<sup>6+</sup> would change as the time went by shown in Table 1 and Chart 1.

**Table 1 Variation of Cr<sup>6+</sup> contents with different Fenton reagents mole ratios in CrCl<sub>3</sub> system (μgCr<sup>6+</sup>/10mL)**

No.	Experimental samples n(Cr <sup>3+</sup> ): n(FeSO <sub>4</sub> ): n(H <sub>2</sub> O <sub>2</sub> )	Reaction time /min					
		0	30	60	90	120	150
1#	5: 1: 1.0	0	2.19	6.08	6.43	7.36	
2#	5: 1: 1.5	0	2.34	14.94	18.35	18.35	20.68
3#	5: 1: 2.0	0	2.19	8.66	17.63	18.20	20.49
4#	5: 1: 2.5	0	2.48	2.69	3.49	5.09	4.81

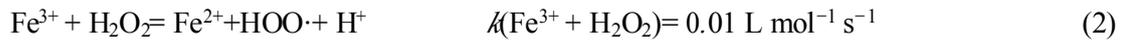
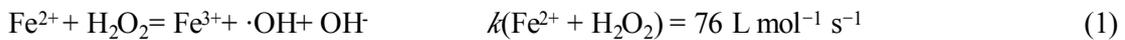


**Chart 1 Relationship of variation of Cr<sup>6+</sup> contents with different Fenton reagents mole ratios in CrCl<sub>3</sub> system as time went by**

### 3.1.2 Discussion and analysis

(1) From Chart 1, it can be seen that Cr<sup>6+</sup> exists in all CrCl<sub>3</sub> solution systems under the condition of different Fenton reagent mole ratios, which showed •OH produced by Fenton reagents could be used as an oxidant which oxidized Cr<sup>3+</sup> to Cr<sup>6+</sup>.

The main reaction mechanisms of Fenton reagents are as follows [4]:



From equation (1), it can be seen that it was hydroxyl radical that made Fenton reagents have stronger oxidability.

From equation (2), it can be seen that in the course of reaction, some peroxide radical (HOO•) was produced at the same time. But the speed constant was the smallest among the above three reactions. The amount of HOO• produced was far less than that of •OH. In addition, an American environment chemist, Zepp G, published one founding article on the oxidability comparison between •OH and •OOH in American *Journal of Science* in 1980. The results show that the oxidability of •OH was about 10<sup>9</sup> times than that of •OOH. Therefore, the main oxidation in Fenton reagent was due to •OH [5].

H<sub>2</sub>O<sub>2</sub>, Cr<sup>3+</sup> and Fe<sup>2+</sup> all existed in CrCl<sub>3</sub> – Fenton solution system. Their standard electrode potentials were as follows: H<sub>2</sub>O<sub>2</sub> + 2H<sup>+</sup> + 2e<sup>-</sup> = 2H<sub>2</sub>O, E<sup>0</sup> = +1.776 V;  
Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup> + 14H<sup>+</sup> + 6e<sup>-</sup> = 2Cr<sup>3+</sup> + 7H<sub>2</sub>O, E<sup>0</sup> = +1.33 V; Fe<sup>3+</sup> + e<sup>-</sup> = Fe<sup>2+</sup>, E<sup>0</sup> = +0.771 V.

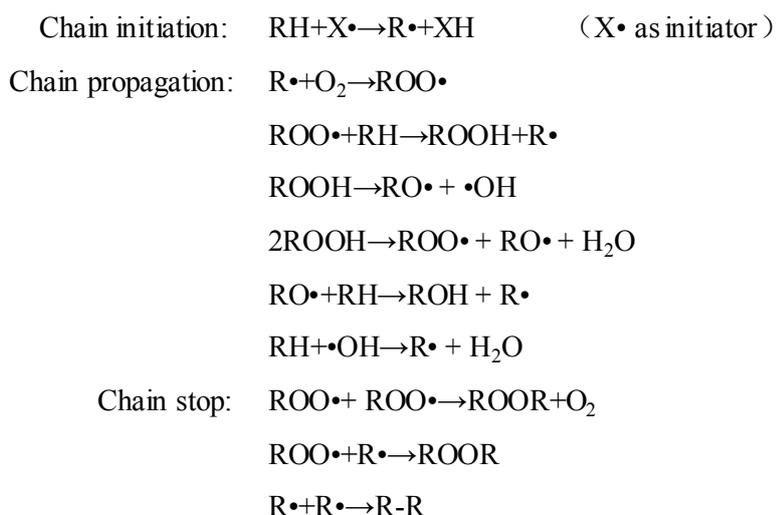
In the acid medium, H<sub>2</sub>O<sub>2</sub> could be used as an oxidant to oxidize Fe<sup>2+</sup> to Fe<sup>3+</sup>, ΔE<sub>1</sub> = 1.776V - 0.771V = 1.005V, and the reaction in dynamics was done quickly (k(Fe<sup>2+</sup> + H<sub>2</sub>O<sub>2</sub>) = 76 L mol<sup>-1</sup> s<sup>-1</sup>). From the point of theory, H<sub>2</sub>O<sub>2</sub> in the acid medium could become an oxidant to oxidize Cr<sup>3+</sup> to Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup>, ΔE<sub>2</sub> = 1.776V -

1.33V=0.446V. Although the reaction could happen in the thermodynamics, Cr<sup>3+</sup> had the very weak reducibility under the acid condition. In the dynamics this reaction could happen very slowly. The oxidation r-reduction reaction usually happened firstly between two bigger electric pairs of  $\Delta E$ . As the above mentioned,  $\Delta E_1 > \Delta E_2$ . The experiment of this article was done in the acid medium (in the system of chrome trichloride solution, at the beginning, pH of the solution was about 2.8). Therefore, in the system of CrCl<sub>3</sub>– Fenton solution, it was Fe<sup>2+</sup> as a reducer that had oxidation-reduction reaction with H<sub>2</sub>O<sub>2</sub>, which got rid of the possibility of H<sub>2</sub>O<sub>2</sub> as an oxidant to oxide Cr<sup>3+</sup> into Cr<sup>6+</sup>.

In the system of CrCl<sub>3</sub>, the production of Cr<sup>6+</sup> ion was resulted from the oxidation of hydroxyl radical produced by Fenton reagent on Cr<sup>3+</sup>, i.e.  $\text{Cr}^{3+} + 3 \cdot \text{OH} = \text{Cr}^{6+} + 3 \text{OH}^-$ .

(2) From Chart 1, it can also be seen that as the increase of H<sub>2</sub>O<sub>2</sub> contents (the mole ratio between H<sub>2</sub>O<sub>2</sub> and FeSO<sub>4</sub> increase to 2.5:1 from 1:1), the Cr<sup>6+</sup> contents produced in this system showed totally the tendency of first rising and then decreasing. That is to say, when H<sub>2</sub>O<sub>2</sub> contents were in a certain range, the Cr<sup>6+</sup> contents in the system increased with the increase of H<sub>2</sub>O<sub>2</sub> contents. When H<sub>2</sub>O<sub>2</sub> contents further increased, Cr<sup>6+</sup> contents in the system decreased obviously.

The studies have found [6,7] that H<sub>2</sub>O<sub>2</sub> concentration increased within a certain range, the production number of  $\cdot\text{OH}$  from Fenton reagent and H<sub>2</sub>O<sub>2</sub> concentration had direct proportion. But when H<sub>2</sub>O<sub>2</sub> concentration was too high, the production number of  $\cdot\text{OH}$  decreased. Because H<sub>2</sub>O<sub>2</sub> amount in Fenton reagent increased to a certain range, the production of hydroxyl radical would increase. Then the oxidation of hydroxyl radical on Cr<sup>3+</sup> became stronger so that Cr<sup>6+</sup> contents increased. Meanwhile, as leather fat liquoring agent (or lipids) molecules had double bonds. In the air, they were very easy to oxide automatically. The reactions were as follows [8,9]:



Among above reactions, RH was lipids and H was a alpha H atom adjacent to the double bond in the lipids. From the above reaction equations, it can be seen that when the hydroperoxide ROOH from the lipids oxidation increased, the more  $\cdot\text{OH}$  radical resolved by ROOH would be, the more of soluble Cr<sup>3+</sup>

in leather would be oxidized to Cr<sup>6+</sup>.

But when H<sub>2</sub>O<sub>2</sub> amount was too much (as No. 4# curve, n(FeSO<sub>4</sub>): n(H<sub>2</sub>O<sub>2</sub>)=1: 2.5), Cr<sup>6+</sup> contents in the system obviously decreased. This was because the production of •OH radical would decrease when H<sub>2</sub>O<sub>2</sub> concentration was too high. Therefore, the ability of Cr<sup>3+</sup> oxidized to Cr<sup>6+</sup> by •OH radical was decreased too. Cr<sup>6+</sup> contents were falling down correspondingly. In addition, H<sub>2</sub>O<sub>2</sub> was not only an oxidant which could oxidize Fe<sup>2+</sup>, but when Cr<sup>6+</sup> in the system was produced and H<sub>2</sub>O<sub>2</sub> concentration was too high, the excessive H<sub>2</sub>O<sub>2</sub> could be a reducer and reacted with Cr<sup>6+</sup> produced in the system so as to make Cr<sup>6+</sup> contents become less in the system. The reaction formula was like:  $Cr_2O_7^{2-} + 4H_2O_2 + 6H^+ = 2Cr^{3+} + 7H_2O + 4O_2$

The factor just brought out negative deviation to the determination of the content of Cr<sup>6+</sup> in Chart 1. So it couldn't lead to the negative effect on the results in Chart 1.

### **3.2 Effect of hydroxyl radical scavenger on the content of Cr<sup>6+</sup> in CrCl<sub>3</sub> solution system.**

#### **3.2.1 Experimental results**

In the solution with mole ratio: n(Cr<sup>3+</sup>): n(FeSO<sub>4</sub>): n(H<sub>2</sub>O<sub>2</sub>) = 5: 1: 1.5, the addition of benzoic acid and the content of Cr<sup>6+</sup> in the system would change as the time went by, shown in Table 2 and Chart 2.

**Table 2 Relationship of variation of benzoic acid addition and Cr<sup>6+</sup> contents in CrCl<sub>3</sub> system as time went by (µgCr<sup>6+</sup>/10mL)**

No.	Experimental samples Benzoic acid (chrome mass %)	Reaction time /h					
		0	30	60	90	120	150
2#	0	0	2.34	14.94	18.35	18.35	20.68
5#	3%	0	2.57	0.89	0.13	0	0
6#	4%	0	1.29	0.61	0.28	0	0

**Chart 2 Variation of benzoic acid addition and Cr<sup>6+</sup> contents in CrCl<sub>3</sub> system as time went by**

#### **3.2.2 Discussion and analysis**

(1) From Chart 2, it can be seen that compared between the system with adding benzoic acid and the system without adding benzoic acid, the Cr<sup>6+</sup> contents in the solution with adding benzoic acid decrease obviously. When the addition of benzoic acid covers 3% of chrome mass and the reaction lasts for 90min, the Cr<sup>6+</sup> contents in the system decrease by 99.3%. This explains that the addition of benzoic acid has clearly the inhibitory action on the production of Cr<sup>6+</sup>.

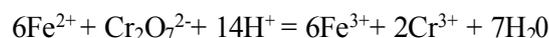
The inhibitory action of benzoic acid on Cr<sup>6+</sup> possibly results from these two causes: on one hand, the Cr<sup>6+</sup> produced in the system is able to have some oxidability, oxidize benzoic acid and consume itself. Since the oxidability of Cr<sup>6+</sup> on benzoic acid is very weak at the room temperature, this factor has a slight effect

on the formation of Cr<sup>6+</sup>.

On the other hand, the benzoic acid added in the system has caught the hydroxyl radical, which keeps Cr<sup>3+</sup> from being oxidized. Benzoic acid is a hydroxyl radical scavenger and it can remove the hydroxyl radical particularly, but has nothing to do with <sup>1</sup>O<sub>2</sub> and H<sub>2</sub>O<sub>2</sub>. Benzoic acid has removed most of hydroxyl radical produced by Fenton reagents in the system. As the extent of Cr<sup>3+</sup> oxidation decreases, the Cr<sup>6+</sup> contents also decrease.

Therefore, benzoic acid affected the catcher of hydroxyl radical and prevents Cr<sup>3+</sup> from being oxidized. This also proves that the hydroxyl radical can become an oxidant for soluble Cr<sup>3+</sup> in the leather and oxidize Cr<sup>3+</sup> to Cr<sup>6+</sup>.

(2) From the curves of No.5# and No.6# in Chart 2, it can be seen that after the addition of benzoic acid, the Cr<sup>6+</sup> contents increase as the time goes by. Up to a certain value, it gradually decreases until disappears. At the initial stage, the rise of the Cr<sup>6+</sup> contents was because some of the hydroxyl radical produced by Fenton reagent was not caught by benzoic acid while this part of hydroxyl radical can oxidize Cr<sup>3+</sup> so as to make the Cr<sup>6+</sup> contents increase bit by bit at the initial period. The Cr<sup>6+</sup> contents reached the highest and then began to decrease until disappeared, which can be caused by the following. First, the intermediate production of benzoic acid having caught hydroxyl radical was phenolic hydroxyl benzoic acid, that is, the phenol substance which is easy to be oxidized. It can not only catch continually hydroxyl radical, but be oxidized into quinones substance by the production of Cr<sup>6+</sup> in the system. Whereas Cr<sup>6+</sup> itself could be reduced to Cr<sup>3+</sup>, so that the Cr<sup>6+</sup> contents decrease. Second, as the concentration of Cr<sup>6+</sup> in the system increases, hydrogen peroxide could become a reducer, which makes Cr<sup>6+</sup> reduce to Cr<sup>3+</sup> so that the Cr<sup>6+</sup> contents in the system decrease. Third, as the increase of the concentration of Cr<sup>6+</sup> in the system, the ferrous ion in the Fenton reagent will become a reducer in the acid solution. Aqueous Cr<sup>6+</sup> can be reduced to Cr<sup>3+</sup><sup>[10]</sup> by aqueous Fe<sup>2+</sup> at a rapid quantitative and stoichiometric reaction.



From the above mentioned three causes, only the first one is involved in benzoic acid. It's thought the first one is the main reason why Cr<sup>6+</sup> contents reached the highest and then began to decrease after the addition of hydroxyl radical scavenger. While the No. 2 #curve without adding hydroxyl radical scavenger shows that in the solution system without adding benzoic acid, the Cr<sup>6+</sup> contents first rises slowly, then rapidly and tends to be stable.

### ***3.3 Effect of hydroxyl radical on the transference of Cr<sup>3+</sup> to Cr<sup>6+</sup> in the system of chrome powder tanning agent solution***

#### ***3.3.1 Experimental results***

In the system of chrome powder tanning agent solution with 4 g/L concentration (measured by Cr<sub>2</sub>O<sub>3</sub>) and mole ratio n (Cr<sup>3+</sup>): n (FeSO<sub>4</sub>): n (H<sub>2</sub>O<sub>2</sub>) = 5: 1:1.5, n (Cr<sup>3+</sup>): n (FeSO<sub>4</sub>): n (H<sub>2</sub>O<sub>2</sub>) = 5: 1:2.0, Cr<sup>6+</sup> in the two

solutions have not been tested out.

### ***3.3.2 Discussion and analysis***

In the system of chrome powder tanning agent solution with 4g/L concentration (measured by  $\text{Cr}_2\text{O}_3$ ),  $\text{Cr}^{6+}$  have not been tested out, which illustrates the chrome powder tanning agent has a certain anti-oxidation, that is to say, the large number of small molecules organic acid in the tanning agent keeps  $\text{Cr}^{3+}$  from being oxidized by hydroxyl radical. Because there are more organic acid radical in the chrome powder tanning agent, they are monocarboxylic acid (such as methanoic acid and acetic acid), dicarboxylic acid (such as oxalic acid and malonic acid), hydroxy acid (such as lactic acid and tartaric acid), and aromatic carboxylic acid (such as o-phthalic acid and terephthalic acid). On the one hand, these small molecule organic carboxylic acids can consume the hydroxyl radical produced from Fenton reagents and be degraded themselves, which is to decrease the oxidant in the system. On the other hand, some of the small molecule organic acid have some reduction capacity, which can reduce  $\text{Cr}^{6+}$  produced from the system to  $\text{Cr}^{3+}$ . Therefore, the small molecule organic acids in the chrome powder tanning agent have the inhibitory action on the formation of  $\text{Cr}^{6+}$  in the system.

## **4 Results**

(1) The experiment has proved that the hydroxyl radical, produced by the unsaturated fat liquor used in the leather making production, could oxidize  $\text{Cr}^{3+}$  to  $\text{Cr}^{6+}$  in system of chrome trichloride. This is one cause that there is trace  $\text{Cr}^{6+}$  in the finished leather.

(2) In the system of chrome trichloride, the concentration of the hydroxyl radical becomes bigger as the  $\text{Cr}^{6+}$  contents increase. The fats and oils contained in fat liquoring agent produced more hydroxyl radical in the process of oxidation, caused the  $\text{Cr}^{6+}$  contents became bigger in the leather.

(3) In system of chrome trichloride, the hydroxyl radical scavenger (benzoic acid) had the obvious inhibitory action on the production of  $\text{Cr}^{6+}$ . When the dosage of benzoic acid was 3% of the chrome mass and the reaction lasts to 90 min, the  $\text{Cr}^{6+}$  contents decreased by 99.3%.

(4) The chrome powder tanning agent has a certain inhibitory action on the oxidation of  $\text{Cr}^{3+}$  by hydroxyl radical.

## **Acknowledge**

This research was supported by National Nature Science Foundation of P.R.China (Item Number: 20676076).

## **References**

[1] C. Z. Yu; P. J. Liu; L. M. Duan; et al. China Leather, 2004, 33(19): 36-40.

- [2] Y. Zhao. *China Leather*, 2005, 34(7): 11-14.
- [3] C. Z. Yu; S. L. Ding; G. X. Sun. *Analysis and Inspection Techniques of Leather*, Beijing: Chemical Industry Press, 2005.
- [4] L. Wang. X. Z. Jiang; Y. J. Liu. *Journal of Hazardous Materials*, 2008, 154: 1106-1114.
- [5] Q. W. Zhao; Y. Liu. *Chemical World*, 2005, 5: 319-320 .
- [6] N. D. Zhang; W. Zheng; Y. Z. Peng. *Analytical Chemistry*, 2003, 31(5): 552-554 .
- [7] L. M. Liu; L. H. Liu; G. W. Song, et al. *Journal of Hubei University (Natural Science Edition)*, 2002: 24(4): 326-328 .
- [8] L. Q. Sun; X. W. Dong; Y. P. Liu. *China Oils and Fats*, 1998, 23(5): 56-57.
- [9] M. Guichardant; M. Lagarde. *Eur. J. Lipid Sci. Technol*, 2009, 111, 75-82.
- [10] Eary, L. E.; Rai, D. *Environ. Sci. Technol.* 1988, 22: 972-977 .