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Research Article / Araştırma Makalesi

REMOVAL OF CAFFEINE AND PARACETAMOL PHARMACEUTICAL RESIDUES BY UV AND UV-H_2O_2

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ABSTRACT

Recently, researchers have shown an increased interest in removal of pharmaceutical residues by advanced oxidation methods because these residues reach up to drinking water supplies and adversely affect them. In this study, it was investigated to remove caffeine and paracetamol by UV and UV-H_2O_2 processes. The inlet and outlet concentrations for each residue were measured by LC-MS/MS instrument. UV and UV-H_2O_2 processes were carried out separately for each pharmaceutical residue. 45% and 100% treatment efficiency were achieved provided for caffeine and paracetamol respectively at the end of 30 minutes processing time in UV reactor alone. It was observed that UV reactor alone is not effective for the removal of caffeine. The UV-H_2O_2 process was applied at different H_2O_2 concentrations. This application is aimed to determine the optimal H_2O_2 concentration for UV-H_2O_2 process. It was shown that the increase in concentration of H_2O_2 affects the removal positively for each pharmaceutical residue. In studies with UV-H_2O_2 process (5 mg/L H_2O_2) for caffeine and paracetamol; at the end of 15 minutes, 99% caffeine and at the end of 7,5 minutes 100% paracetamol removal were achieved. The results show that UV-H_2O_2 process provides more effective treatment for pharmaceutical residues than UV process alone. Higher removal efficiency needs longer reaction time in UV reactor and in this method wouldn't be economical. Additionally, paracetamol could be removed in less time than caffeine in both processes.
Keywords: Caffeine, paracetamol, UV, UV-H_2O_2.

1. INTRODUCTION

Previous studies in various European countries have reported that more than 100 pharmaceutical compounds are found in the waters of treatment plant, in surface and underground waters [1]. The potential effects of these compounds on the environment are generally unknown [2]. Pharmaceuticals are produced intestinally to be stable for long period storage and to be eaten up easily. They are lipophilic enough to cross membranes and must be resistant to enzymes, especially those taken orally, so that they can reach to effect points. They must be hydrolyzed at acidic pH value. Active pharmaceutical ingredients and by- products used for human and animal diseases can cause adverse effects on aquatic or terrestrial ecosystems because of these properties [3-4].

Although many of pharmaceuticals can be treated at a certain level in classical wastewater treatment plants, some of them cannot be treated at all due to chemical structures. Conventional

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sewage treatment pl ants are not specifically designed for the efficient and complete removal of pharmaceuticals [5]. These residual pharmaceuticals are eventually discharged into the aquatic environment [6-7]. Even at low concentrations, pharmaceuticals are suspected to pose a threat to the aquatic environment due to their high bioactivities [8]. To deal with this problem, advanced oxidation processes (AOPs) have recently gained recognition as a promising approach [5, 9, 10, 11].

The studies related to removal rates of pharmaceuticals in treatment plants are mostly based on the measurement of pharmaceutical concentrations in the inlet and outlet water. Removal rates vary widely depending on the treatment technology, hydraulic retention time, seasonal conditions and performance of treatment plants [1, 4, 12, 13].

Advanced oxidation processes are the most commonly used methods for the removal of pharmaceutical residues. However, studies on this subject continue in detail about the chemical structure of the pharmaceutical residue and the interactions of the pharmaceuticals with each other.

The degradation of recalcitrant pollutants by AOPs is based on highly-reactive hydroxyl radicals (OH radicals) that have the capability for total mineralization of a variety of organic compounds with high reaction rate constants, generally around 109 L/mol/s [5-14]. The hydroxyl radical enters the reaction faster than ozone and hydrogen peroxide and greatly reducing treatment costs and system size. In addition, hydroxyl radical is a strong and non-selective chemical oxidant [15]. This radical is a strong oxidizing agent for synthetic and natural organic compounds which cannot be removed by other methods in the water [16]. Advanced oxidation processes have fewer operating problems and provide higher treatment yields [17].

Two hydroxyl radicals are formed with hydrolysis of H_2O_2, under UV irradiation. The resulting radicals react with organic pollutants or carry out a H_2O_2 degradation-formation cycle [18]. This chemical reaction may be shown in Eq. (1)-(3) below.

$$H_2O_2 + hv \rightarrow 2OH^{\bullet} \quad (1)$$

$$H_2O_2 + OH^{\bullet} \rightarrow H_2O + HO_2 \quad (2)$$

$$HO_2 + HO_2 \rightarrow H_2O_2 + O_2 \quad (3)$$

Benitez et al. (1996) pointed out that this degradation-formation cycle of H_2O_2 is used to express an H_2O_2 concentration nearly the constant during treatment. It is noteworthy that the excessive doses of H_2O_2 can prevent radical degradation. On the other hand, sufficient amount of H_2O_2 is necessary because it can absorb UV which accelerates hydroxyl production [19].

One of the most important problems of the advanced oxidation processes with UV light is that the UV sources require high electrical energy and therefore high operating costs. Because of this reason, minimizing the reaction time and other operating conditions (pH, chemical selection and concentration, contaminant ratio etc.) should be optimized [20]. The aim of this study is to investigate the optimum operating conditions of the removal of caffeine and paracetamol residues by UV and UV/H_2O_2 processes.

2. MATERIALS AND METHODS

2.1. Analyses of Caffeine and Paracetamol Pharmaceuticals

In the scope of the study, we choose the products that are available and frequently used in the market of which active ingredients are caffeine and paracetamol. These are: 'Ergafine' for caffeine and 'Parol' for paracetamol. 1,7 dimethylxanthine was studied as a by-product of caffeine. Following this, tablet weights of each of the pharmaceuticals were determined and pulverized. Stock solutions are prepared with ultrapure water according to calculations for the amount of active pharmaceutical in each tablet. Prepared stocks were diluted with tap water to get desired concentrations. The results obtained from analysis of tap water are shown in Table 1.

Table 1. Characteristics of tap water used in study

Parameters	Analyses Number (n)	Average±standart deviation
pH	5	7.62±0.08
EC(µS/cm)	5	735.20±26.16
Hardness (mg/L $CaCO_3$)	5	259.00±8.49
Alkalinity (mg/L$CaCO_3$)	5	211.40±7.40
Turbidity(NTU)	2	17.5±3.54
TOC	5	5.29 ±3.46
TN	4	0.95±0.41
NH_4-N	5	≤0.05
SO_4	5	36.46±3.45
UV Absorbance (254 nm)	5	0.024±0.001

2.2. Experimental Setup for UV and UV / H_2O_2 Processes

Tetra-Perfect 01 model, 50 Hz, 220 V, 254 nm wavelength light emitting UV reactor was used in the study. The prepared pharmaceutical solutions were pumped to the UV reactor with a Velp Scientifica SP311 model peristaltic pump. The pump was operated at 10 rpm. The pharmaceutical solutions in a volume of 350 mL were exposed to UV light for 30 minutes. Details of the experimental set-up are shown in Fig.1. Following this, pharmaceutical concentrations in the samples taken from the inlet and outlet of the reactor were measured by an LC-MS/MS instrument. The removal efficiencies for each pharmaceutical were calculated according to the obtained results.

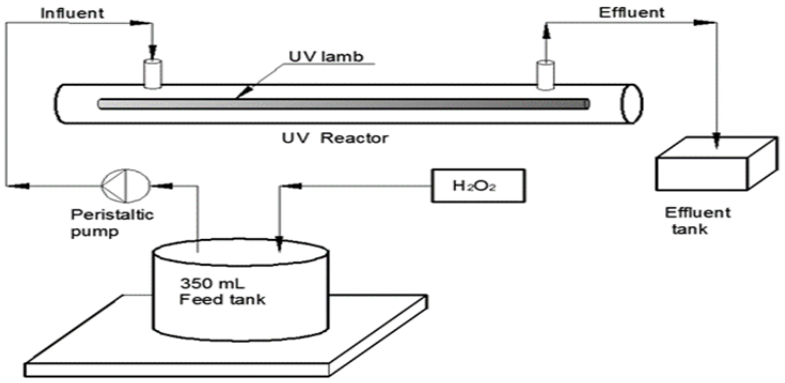

Figure 1. Experimental set-up for UV/H_2O_2 process

The H_2O_2 (100 mg/L) stock solution was added to the pharmaceutical solutions before being fed to the UV reactor in the UV/H_2O_2 process. The UV/H_2O_2 process was studied at 1, 3, 5 and 7 mg/L H_2O_2 concentration. H_2O_2 stock solution was prepared using 30% H_2O_2 with a density of 1.11 g/cm^3 obtained from Merck. All of these operations were carried out on a magnetic stirrer and the inlet-outlet pH values were measured. Our aim of this experimental study is to determine which of the two processes more effective in the removal of pharmaceutical residues. In addition, optimum operating conditions have been determined for each process.

2.3. LC-MS/MS Measurements

The inlet and outlet concentrations of all pharmaceuticals were measured by LC-MS / MS. The instrument consists of Thermo Scientific TSQ Quantum Access Max mass spectrometry and Thermo Scientific Ultimate 3000 HPLC. In the LC-MS/MS analyses, pure methanol (phase B) and 0.1% formic acid (Phase A) were used as mobile phases. The methanol and formic acid were acquired from Merck at MS purity. Mobile phases filtered and degassed to avoid air bubbles before used in the LC-MS/MS. Pharmaceutical residues were measured in positive mode, electrospray ionization (ESI) mass spectrometer. As the column, BDS HYPERSIL C18 (100 mm × 4.6 mm × 5 µm) was preferred and it was run in 0.4 µL/min flow according to column. In the next step, optimization studies were carried out for the pharmaceutical planned to be analyzed. The aim of the optimization studies is to determine the optimal working values for the pharmaceuticals in the LC-MS/MS and to introduce the pharmaceutical to the instrument.

3. RESULTS AND DISCUSSION

In this study, the UV process was first tested and then UV/H_2O_2 process was tested separately for each pharmaceutical residues. Peak formations in the LC / MS-MS of the analyzed drugs are given in Appendix A. The results obtained for the study of caffeine are shown in Fig. 2. As shown in Fig. 2, approximately 99% removal efficiencies of caffeine were obtained after 15 minutes in the UV-H_2O_2 process at a concentration of 5 mg/L H_2O_2. In case of using UV alone, caffeine was removed only 45% at the end of 30 minutes. These results show that UV-H_2O_2 process is more effective than UV process for caffeine.

In the second step, the effect of H_2O_2 concentration on removal efficiency in the UV-H_2O_2 process was investigated. In the same experimental conditions, UV-H_2O_2 processes were repeated at concentrations 1, 3 and 7 mg/L H_2O_2 concentrations. As can be seen from Fig. 3, caffeine removal efficiency also increased with H_2O_2 concentrations and time. 100% removal efficiency was observed in UV-H_2O_2 process with 7 mg/L H_2O_2 at the 15th minute. 1,7-dimethylxanthine by-product of caffeine were not found in the output samples in which the caffeine residues are detected.

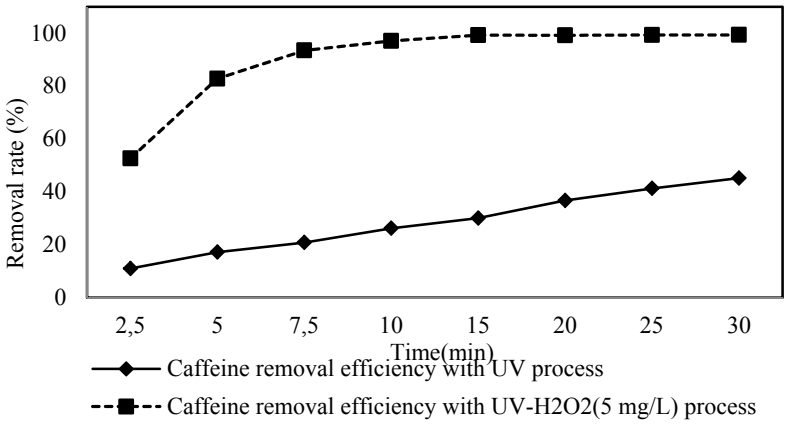

Figure 2. Comparison of UV and UV-H_2O_2 processes in caffeine removal rate.

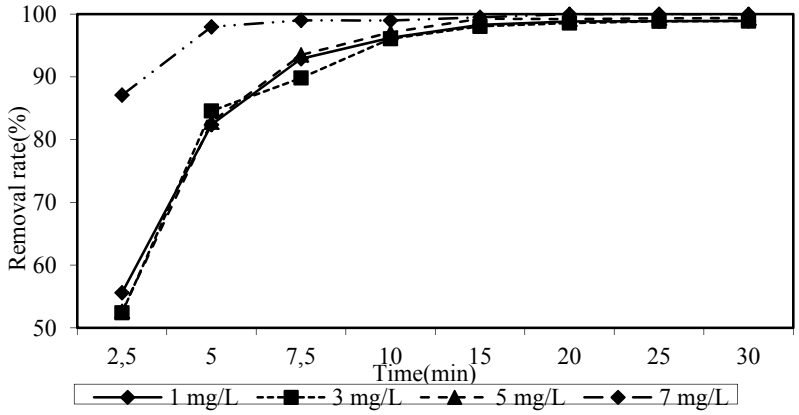

Figure 3. Comparison of UV-H_2O_2 processes at different H_2O_2 concentrations (1-3-5-7 mg/L) in caffeine removal rate

In a previous work, Kim et al. (2009) investigated the effect of H_2O_2 addition on the photo protection characteristics of PPCPs and pharmaceutical during UV treatment. They found that degradation of PPCPs were increased by adding H_2O_2 to the UV process [21].

In another study, some selected pharmaceuticals were investigated by various chemical treatment methods. The degradation of the pharmaceutical was studied by UV, ozone, Fenton, Fenton-like system, Photo-Fenton and UV -ozone in combination with H_2O_2, TiO_2, Fe (II), Fe (III). Each process was tested separately and the removals were evaluated. According to the results of the study, a second oxidant increased the oxidation rate [22]. In this study, the process in which UV was used with H_2O_2, the removal yield was increased in both pharmaceutical.

In the second phase of the study, all studies were repeated for the removal of paracetamol residues. All process conditions (UV reactor, temperature, pH, time and sample volume) were the same as those performed with caffeine. The results obtained for the UV-H_2O_2 process with 5 mg/L H_2O_2 and UV alone were the presented in Fig.4.

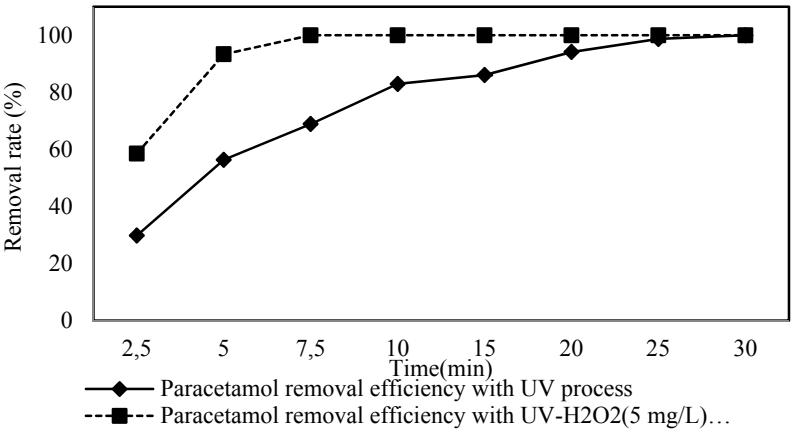

Figure 4. Comparison of UV and UV-H_2O_2 processes in paracetamol removal rate.

In UV and UV-H_2O_2 (5 mg/L H_2O_2) processes applied to paracetamol residues, higher removal rates were obtained compared to caffeine residues. This difference can be caused by different chemical structures of pharmaceuticals. At the end of 30 minutes, 100% paracetamol removal was obtained in the UV reactor without H_2O_2 addition. In the process of UV treatment with 5 mg/L H_2O_2, 100% removal was achieved at the end of 7.5 minutes. This rate was determined as 99.2% at the end of 15 minutes for caffeine.

As shown in Fig. 4, the UV-H_2O_2 process provided much higher removal of paracetamol than the UV reactor. Thus, the results of the analyses demonstrate that UV-H_2O_2 process is more effective than UV reactor for all pharmaceuticals investigated for removal efficiency are presented.

In the last phase of the study, different H_2O_2 concentrations were tested for the UV-H_2O_2 process for paracetamol residues and the effect of varying H_2O_2 concentrations on the process was investigated. The results obtained were shown in Fig.5.

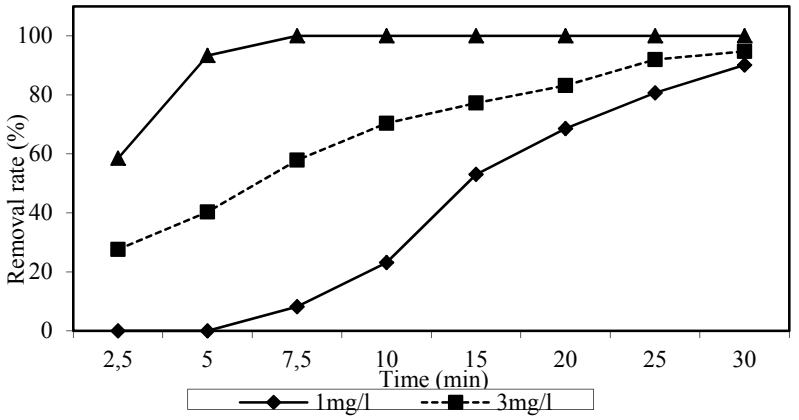

Figure 5. Comparison of UV-H_2O_2 processes at different H_2O_2 concentrations (1-3-5 mg/L) in paracetamol removal rate

As seen in Figure 5, as the concentration of H_2O_2 increases, the rate of paracetamol removal increases significantly. The 100% paracetamol removal was achieved at 5 mg/L H_2O_2 at the end of 7.5 minute. The positive effect of the increase in H_2O_2 concentration was clearer in the removal of paracetamol residues than that of caffeine.

It is important to note here that the excess H_2O_2 dose can prevent radical degradation. On the other hand, sufficient amount of H_2O_2 is necessary because it can absorb UV which accelerates hydroxyl production [22]. This situation was also observed in the study results. A further increase in H_2O_2 concentration after certain levels for each pharmaceutical residue did not increase the treatment yield.

3. CONCLUSIONS

In this study, removal of caffeine, 1,7 dimethylxanthine and paracetamol pharmaceutical residues by UV and UV-H_2O_2 processes were investigated. In addition, optimum working conditions were determined for which the maximum removal was achieved for these pharmaceuticals in both processes. At the end of the study, the use of UV reactor provides 100% removal of only paracetamol residues. This was only realized at the end of the 30-minute process time. For caffeine residues it is 45% after 30 minutes. These results indicate that the use of UV alone can achieve very low removal rates compared to the UV-H_2O_2 process and longer reaction

times are required for higher removal yields. The reactors to be designed in this way may not be economical to use.

In the overall, the lowest removal was observed in both processes for caffeine. 99% removal was achieved from the 15th minute in the UV / H_2O_2 process for caffeine residues. This removal rate is quite high compared to the UV process. The UV / H_2O_2 process resulted in 100% removal in 7.5 minutes for paracetamol. These results show that the UV / H_2O_2 process provides much shorter times and higher removal efficiencies than UV processes in the removal of pharmaceutical residues. For this reason, it is necessary to minimize the reaction time

One of the most important problems of advanced oxidation processes with UV light is that UV sources require high electrical energy and hence high cost. In order to minimize this disadvantage, the UV reactor is used in combination with H_2O_2 to achieve more efficient removal in shorter process times. The presence of H_2O_2 was observed to have a considerable positive effect on removal. To obtain different percentages of removal from pharmaceuticals under same conditions can be caused by having different chemical structures.

Acknowledgments

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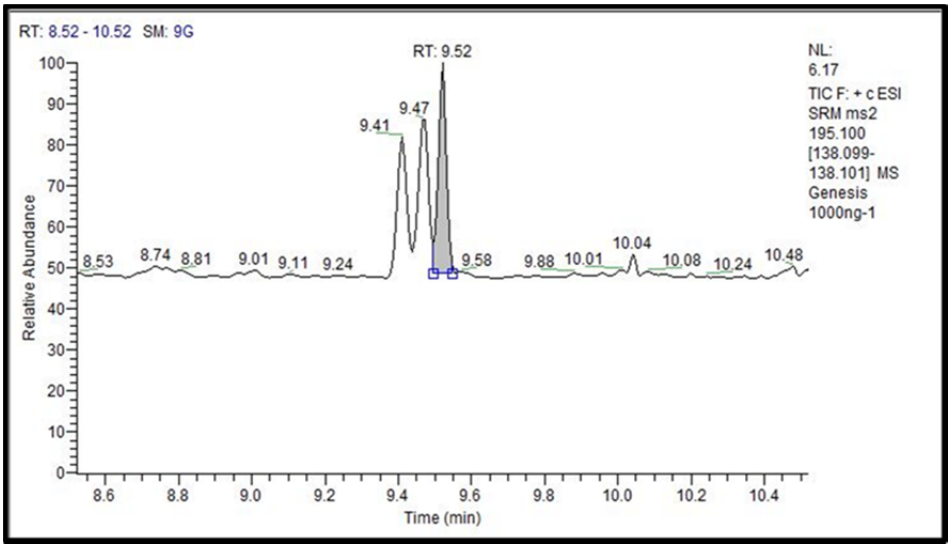
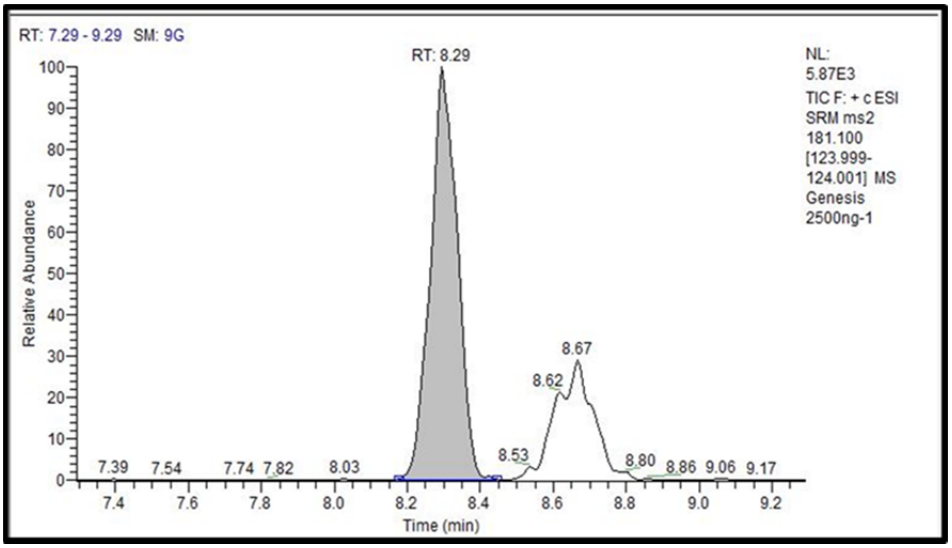
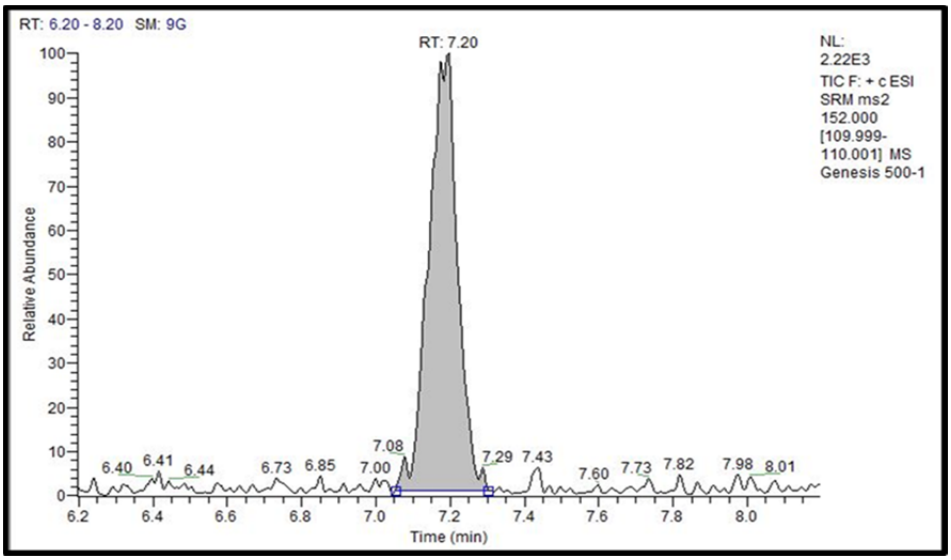
Appendix A.



A.1 Chromatogram of 1000 ng caffeine standard solution.



A.2 Chromatogram of 2500 ng 1,7 Dimethylxanthine standard solution



A.3 Chromatogram of 500 ng paracetamol standard solution