

Full Paper

All Solid State Potentiometric Sensors for Granisetron Hydrochloride in Pharmaceutical Formulation

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Abstract- Granisetron content of some pharmaceutical tablets was determined using a novel all-solid-state polymeric-membrane-electrode (ASS-PME) having a sensing element functioning based on an ion-exchange mechanism. The best results were observed with ASS-PMEs containing 8% GST-tetrakis (p-chlorophenyl) borate as the ion-pair, 56% of dibutyl phthalate, 31% of poly(vinyl chloride), 3% of an ionic liquid and 2% of KpCITPB. The ASS element of the device was a conductive composite of graphite, MWCNTs, and an epoxy resin coated on a copper wire, and the PVC membranes were coated on the ASS. The ASS-PME showed a Nernstian response of 58.1 ± 0.2 mV/decade over the range of 1.0×10^{-6} to 1.0×10^{-3} M. The application of the device was validated and the method was found to be applicable in the analysis of Granisetron hydrochloride in pharmaceutical formulations.

Keywords- Sensor, Granisetron, Polymeric membrane, All solid state, Potentiometry, Pharmaceutical formulation

1. INTRODUCTION

1-methyl-N-(endo-9-methyl-9-azabicyclo[3.3.1] non-3-yl)- 1H-indazole -3-carboxamide or Granisetron (GST) (Fig. 1), is an orally or intravenously administered serotonin type 5-HT₃ receptor antagonist used for preventing nausea resulting from chemotherapy, radiotherapy as well as post-operative nausea in patients [1,2]. GST has been found to cause less side effects, a better tolerability profile, less drug interaction risks, and a longer duration of action as opposed to other 5-HT₃ receptor antagonists. The metabolism of GST in human body, mainly happens through aromatic hydroxylation leading to the formation of 7-hydroxygranisetron (metabolite D), which is a pharmacologically active metabolite and is subsequently conjugated.

GST concentration in biological samples has reportedly been determined through techniques including liquid chromatography [3,4], and tandem mass spectrometry [5] UV spectroscopy [6,7]. There is also one report on the determination of GST using a PVC membrane electrode which is a symmetric membrane electrode with linear range of 1.0×10^{-5} to 1.0×10^{-2} M [8].

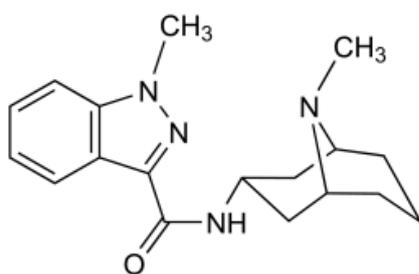


Figure 1. Chemical structure of Granisetron

While instrumental techniques offer advantages like high sensitivity and low detection limits (DLs), potentiometric methods have been known to enjoy the advantages of ease of use, rapid and low-cost analysis, wide response range, and good selectivity, as well as being portable, which make them promising candidates for the determination various compounds including the active ingredients of pharmaceutical formulations [9-13].

Potentiometric ion-selective electrodes (ISEs) constitute a range of electrochemical sensors [14-25], including PVC membrane electrodes (PMEs), coated wire electrodes (CWE), carbon paste electrodes (CPE), all-solid-state electrodes (ASS) and field effective transistors (FET). The devices can also be classified as being structurally symmetric or asymmetric sensors. By definition, symmetric devices are those in which the PVC membrane is located between the sample and an internal standard solution. In asymmetric devices, on the other hand, the inner side of the membrane is in direct contact with a solid element (i.e the transducer) and hence the inner solution is eliminated. Although the detection limits of symmetric are usually in the range of 10^{-5} to 10^{-7} M, those of asymmetric devices like CWEs

are improved and reach around 10^{-8} M or lower. Asymmetric devices are also known to have enhanced mechanical stability.

ASS-PME [26-30] are other members of the asymmetric electrode family [31-34], in which the solid transducer is a conductive composite of graphite mixed and an epoxy resin that is further coated with a PVC membrane.

The focus of the present work, has hence been the development of an ASS-PME for the selective potentiometric determination of GST in pharmaceutical formulations over a wide concentration range, based on an ion-exchange mechanism. This was achieved through the preparation of an ion-pair compound and its application to prepare a polymeric membrane. The method based on the application of the ASS-PME was next validated and used for the determination of Granisetron hydrochloride in corresponding tablets.

2. EXPERIMENTAL SECTION

2.1. Apparatus and measurements

The measurements were performed using the ASS-PMEs as the indicator electrodes, and an Ag/AgCl electrode (Azar-Electrode Co., Iran) as the reference electrode. The two electrodes were linked using a 250 pH/mV meter (± 0.1 mV) and the cell was used in the following assembly during the measurements:



All measurements were performed by calibration method using several standard solutions.

2.2. Materials and Reagents

Analytical reagent grade chemicals (sodium tetraphenyl borate (NaTPB), potassium tetrakis (p-chlorophenyl) borate (KTPCIPB), dibutyl phthalate (DBP), nitrobenzene (NB), dibutyl sebacate (DBS), benzyl acetate (BA), *o*-nitrophenyloctylether (*o*-NPOE), room temperature ionic liquids, 1-n-butyl-3-methylimidazolium tetrafluoroborate ([bmim]BF₄), 1-n-butyl-3-methylimidazolium hexafluorophosphate ([bmim]PF₆), tetrahydrofuran (THF), solvents, nitrate or chloride salts, and 1–2 μm graphite powder) were obtained from Merck Co, and were of the highest purity available. High-molecular weight PVC was procured from Fluka Co., and the multi-walled carbon nanotubes (MWCNTs) 10-40 nm diameters, 1-25 μm length, core diameter: 5-10 nm, SBET: 40-600 m^2/g , V_{total} : 0.9 cm^3/g , bulk density 0.1 g/cm^3 , true density 2.1 g/cm^3 and with 95% purity were from the Research Institute of the Petroleum Industry (RIPI), Tehran, Iran. The macroplast Su 2227 epoxy and desmodur RFE hardener were from Henkel and Bayer Ag (Germany), respectively. Granisetron hydrochloride was from Sigma-Aldrich and the GST tablets were obtained from a local pharmacy.

2.3. Preparing the ion-pair complex (IPC)

To prepare the IPC solutions of granisetron hydrochloride and a proper salt (e.g. sodium tetraphenyl borate or potassium tetrakis (*p*-chlorophenyl) borate were used. Both sodium tetraphenyl borate (NaTPB) and potassium tetrakis (*p*-chlorophenyl) borate, are suitable for this application due to the fact that they have large hydrophobic anions (Fig. 2) and small inorganic cations. Such salts are commonly used as precipitating reagents in inorganic or organometallic experiments [10].

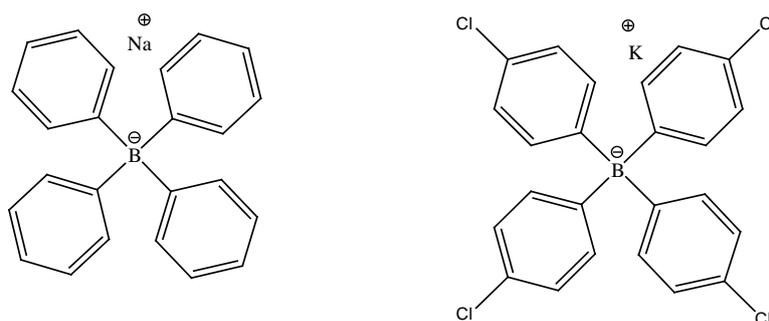


Figure 2. Chemical structure of ionic additives

More specifically, the IPC was synthesized by adding a solution of 50 mg of the organic salt in 5 mL of distilled water to that of a 50 mg GST.HCl in 15 mL distilled water. The resulting precipitate was filtered, washed with water, and then stored in room temperature to dry.

2.4. Making the sensors

The polymeric membrane was prepared through add-mixing known amounts of the IPC, PVC, the plasticizer, and the ionic additives in tetrahydrofuran (THF) into a glass dish of 2 cm diameter. The mixtures were slowly heated to evaporate their THF content to yield an oily solution.

To prepare the ASS element, the composite of the graphite, MWCNTs and the epoxy resin were prepared and coated on the copper wire. The mixtures were prepared in THF and rested for about 20-30 minutes, and the resulting viscose mixture was coated on the copper wire. A 0.5 mm × 15 cm shielded copper wire was used to this end and it was polished and dipped in to the composite mixture 10 times, so that the wire was covered with the mixture. The assembly was allowed to dry for about 10 h. Different amounts of graphite powder, MWCNTs, epoxy, and hardener were used and based on the results the optimal all solid state elements were found to be those with 30% and 15% wt. of the epoxy resin and the hardener, 5% wt. of MWCNTs and 50% wt. of graphite powder in THF.

Once the all-solid state element was ready it was then dipped into the PVC membrane

mixture 3 times and then allowed to dry in air for one day. The final ASS-PMEs were finally conditioned in a 10^{-3} M solution of GST.HCl.

2.5. Preparation of GST solutions

A 0.1 M solution of GST in distilled water was prepared used as the stock solution for making the 1×10^{-8} to 1×10^{-2} M solutions used. All solutions were stored at 4°C in a refrigerator.

To make the samples ready for analysis, 20 tablets each containing 1mg GST.HCl were ground and appropriate amounts of powder were carefully weighed and transferred into a 10-mL volumetric flask and dissolved in an acetate buffer (0.1 M; pH=4) and diluted to the line. The samples of this stock solution were filtered using a 0.45 mm Millipore filter.

3. RESULTS AND DISCUSSION

Although membrane sensors constitute rapid, simple and inexpensive tools for the analysis of different drugs, yet they do not necessarily show equal sensitivity as opposed to instrumental methods. Clearly, the most important element of the ASS-PME is the polymeric membrane which can directly influence the performance of the sensor.

3.1. The composition of the polymeric membranes

The nature, amount and ratio of the components of the PVC membrane directly influences the sensor performance and should hence be optimized. Table 1 provides a summary of the different membrane compositions. In all cases the PVC content was 31% wt. and the plasticizer/polymer ratio was kept at the optimal value of 2 [8-15].

It is well-established that the solvent mediator, which is a water-immiscible organic solvent with low vapor-pressure, used in the membrane composition and its nature can influence the mobility of the sensing material [10-12]. The solvent mediator should also be inert and not have functional groups. Different plasticizers with various dielectric constants (e.g. dibutyl sebacate (DBS;DC: 4.5); dibutyl phthalate (DBP; DC: 6.4); nitrophenyloctyl ether (*o*-NPOE; DC: 24); nitrobenzene (NB; DC: 35.7); and benzyl acetate (BA; DC: 5.7)) were used in the preparation of the PVC membranes and the results in Table 1, clearly show that membranes 3 to 8, based on DBP revealed better performances as compared with the other, given that GST is a hydrophobic compound and plasticizers with lower dielectric constants are expected to extract such cations into the membrane better.

Ionic additives, on the other hand, are used in small amounts to lower the Ohmic resistance of polymeric membranes. The concentration of these additives should however not certain amounts exceed since they may act as ion-exchangers [34]. Given that room temperature ionic liquids (RTILs) have been reported to be applicable as ionic additives, some RTILs were tested in the membrane compositions and based on the results in Table 1

(compositions 11-15) [bmim]PF₆ was found to lead to better results in comparison to the other RTILs. Yet, using a combination of RTILs with a cationic additive (membrane no.16) was found to produce the best responses.

Table 1 also shows that the membrane without the IPC (no. 18) produces no response. Based on the overall results, membrane no. 16 (containing 8% wt. of the ion-pair, 56% wt. of DBP, 31% wt. of PVC, 2% wt. of KpCITPB, and 3% wt. of [bmim]PF₆) was considered as the optimal composition with a slope of 58.1±0.2 mV per decade.

Table 1. PVC membrane compositions used in GST ASS-PMEs

No	Composition of the membrane			Characterization of AAS-PME		
	Plasticizer	Ion-pair	Ionic Additive	Slope mV/decade	DL (M)	Response time
1	DBP,65	4	-	22.8±0.4*	1.0×10 ⁻⁴	85 s
2	DBP,63	6	-	30.5±0.3	5.0×10 ⁻⁵	65 s
3	DBP,61	8	-	47.7±0.5	2.0×10 ⁻⁵	55 s
4	DBP,60	9	-	47.5±0.7	2.0×10 ⁻⁵	55 s
5	DBS,61	8	-	47.0±0.4	2.0×10 ⁻⁵	56 s
6	NPOE,61	8	-	35.5±0.3	4.0×10 ⁻⁵	70 s
7	BA,61	8	-	44.4±0.7	2.0×10 ⁻⁵	57 s
8	NB,61	8	-	33.2±0.4	3.0×10 ⁻⁵	75 s
9	DBP,59	8	2 KpCITPB	53.1±0.5	1.0×10 ⁻⁶	44 s
10	DBP,59	8	2 NaTPB	52.4±0.3	1.0×10 ⁻⁶	45 s
11	DBP,60	8	1 [bmim]PF ₆	51.1±0.3	3.0×10 ⁻⁶	44 s
12	DBP,60	8	1 [bmim]BF ₄	50.9±0.4	3.0×10 ⁻⁶	44 s
13	DBP,59	8	2 [bmim]BF ₄	54.0±0.2	1.0×10 ⁻⁶	40 s
14	DBP,59	8	2 [bmim]PF ₆	54.3±0.3	1.5×10 ⁻⁶	38 s
15	DBP,58	8	3 [bmim]PF ₆	54.3±0.4	1.0×10 ⁻⁶	36 s
16	DBP,57	8	2 KpCITPB, 2 [bmim]PF ₆	58.1±0.2	7.0×10 ⁻⁷	25 s
17	DBS,57	8	2 KpCITPB, 2 [bmim]PF ₆	57.7±0.3	8.0×10 ⁻⁷	27 s
18	DBP,65	0	2 KpCITPB, 2 [bmim]PF ₆	12.1±0.5	3.0×10 ⁻⁴	95 s

*standard deviation of five repeated measurements

3.2. Calibration curves

Using the optimal membrane, different GST.HCl solutions were analyzed and the results were used to plot an E vs. $-\log [GST]$ curve (Figure 3). The response of the sensor was found to be linear in the range of 1.0×10^{-6} to 1.0×10^{-3} M. The slope of the calibration curve was also found to be 58.1 ± 0.2 mV per decade of concentration and the DL of the ASS-PME was also determined to be around 7.0×10^{-7} M.

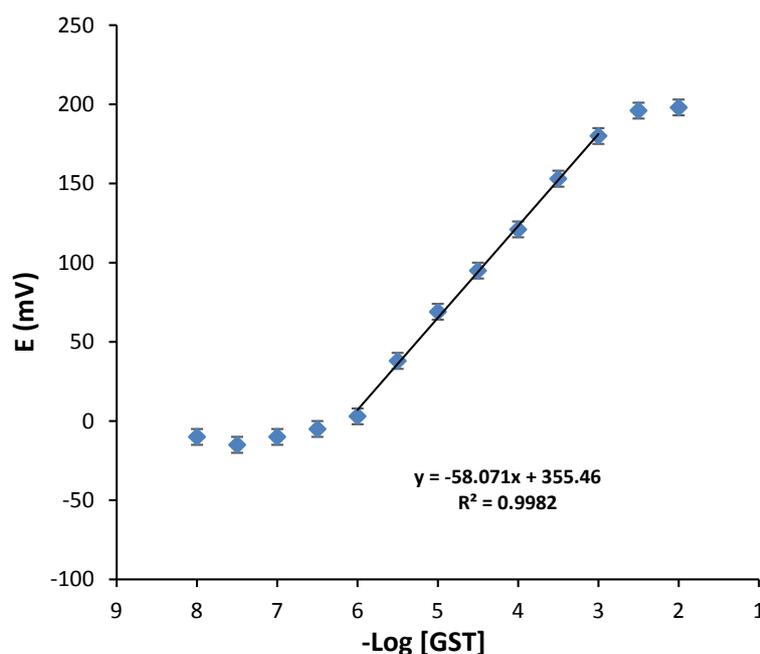


Figure 3. Calibration curves of GST potentiometric sensors; each points are averaged of five replicate measurements.

3.3. Response Time

The response time of the ASS-PME was also determined through a set of experiments. Based on definition, the response time of a potentiometric sensor is the time required for reaching to a potential within ± 1 mV of the new equilibrium potential, after a ten-fold change in the concentration of the solution. To determine this parameter, sensors are successively immersed in a series of analyte solutions with ten-fold concentration differences and the time required for reaching the equilibrium value is measured [35-39]. In this experiment, the concentrations of the GST solutions were in the range of 1.0×10^{-6} to 1.0×10^{-2} M and the sensor was found to be capable of reaching its equilibrium response through the whole concentration range in a rather short period of 25 s, which was hence reported as the response time of the electrode.

3.4. pH Effect on the response of the ASS-PME

The effect of pH on the responses of the optimal ASS-PME was evaluated at two GST concentrations of 1.0×10^{-3} , and 1.0×10^{-5} M, while varying the pH of the solution from 1.0 to 10.0 using concentrated NaOH or HCl solutions to avoid considerable concentration changes. The results plotted in Fig. 4, show that the response of the ASS-PME was pH-independent in the range of 2.8 to 6.0 with both solutions. The changes in the electrode response both above and below this range can be attributed to the removal of the positive charge of the cations and its lower solubility at higher pH as well as leaching of the membrane components or the analyte in the solution, at lower pH, respectively.

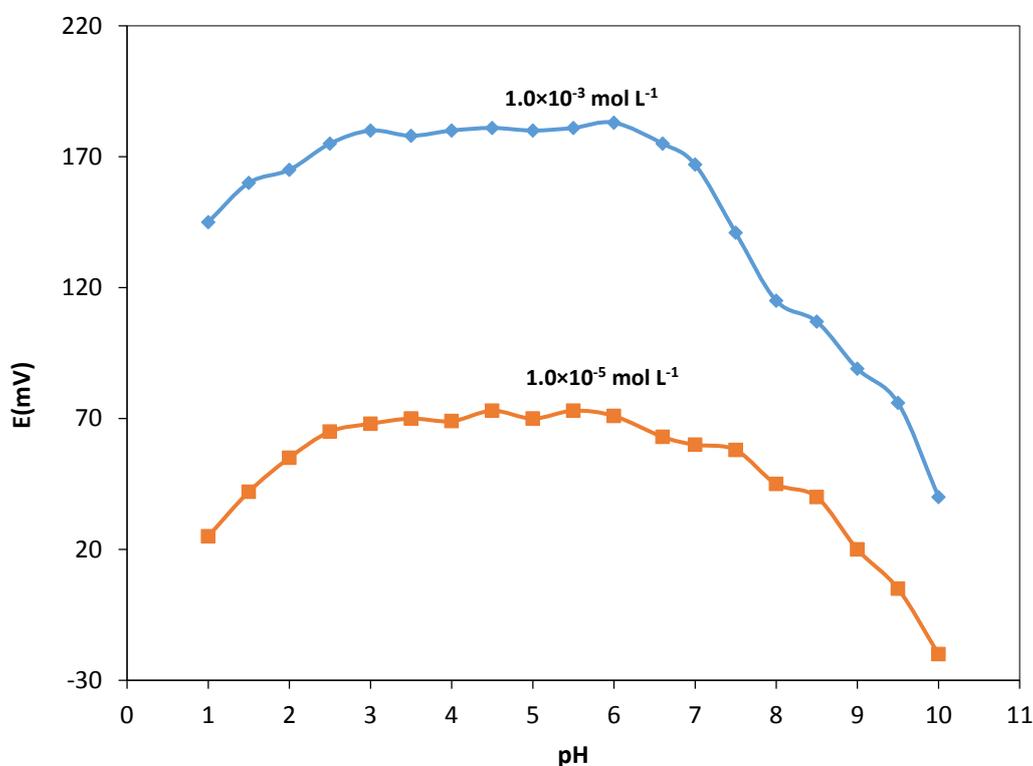


Figure 4. The effect of pH on the electrode response in 1.0×10^{-3} and 1.0×10^{-5} M solutions

3.5. Life-time

To evaluate the durability of a potentiometric sensor changes in its Nernstian slope and detection limit can be monitored. In the case of the developed ASS-PME, three electrodes were used for evaluation. The evaluation protocol included testing each electrode for 1 hour per day during a 10-week period. Based on the observations on the changes in the slope and detection limit (Table 3) the lifetimes of all three detectors were determined to be in the range of 4–10 weeks [36–39]. The results revealed that after 8 weeks, the potential slopes of the electrodes started to gradually decrease while their DLs increased.

All these were attributed to the loss of the polymeric membrane ingredients into the solution due to repeated usage.

Table 3. Lifetime of ASS-PME

Week	ASS-PME	
	Slope (mV per decade)	DL (M)
First	58.1±0.2	7.0×10 ⁻⁷
Second	58.0±0.3	7.5×10 ⁻⁷
Third	57.5±0.2	7.5×10 ⁻⁷
Fourth	57.0±0.1	8.0×10 ⁻⁷
Fifth	57.0±0.3	9.0×10 ⁻⁷
Sixth	56.3±0.2	9.0×10 ⁻⁷
Seventh	56.1±0.4	9.5×10 ⁻⁷
Eighth	56.0±0.2	9.5×10 ⁻⁷
Ninth	45.2±0.3	2.5×10 ⁻⁶
Tenth	38.8±0.4	7.0×10 ⁻⁶

3.6. Analytical characterization of the sensors

To assess the analytical applicability of the electrodes, they were used for the analysis of GST concentration in solutions of pharmaceutical tablets. During the tests the linear range, detection limit, selectivity, precision, accuracy, and ruggedness/robustness of the ASS-PMEs were determined.

The results of the analysis of the tablet solutions are summarized in Table 4. The analyses were performed through the calibration method and the results were found to fully comply with those obtained through a standard HPLC method.

To assess the selectivity behavior of the sensor, in terms of the selectivity coefficients, defined as its tendency to respond to the analyte as opposed to other interfering species present. Different routines have been reportedly used for the determination of selectivity coefficients, among which the matched potential method (MPM) [40-43], was used in this work. The resulting MPM selectivity coefficients are summarized in Table 5, which clearly indicates that the tested ionic and non-ionic interfering species do not pose serious interferences to the analysis results.

Table 4. Measurement of GST.HCl in some pharmaceutical formulations by the proposed sensor and standard method

Sample	Labeled amount (mg/tab.)	Found by the ASS-PME* (mg/tab.) n=5	Standard method n=5	t-test (p-value: 0.05; $t_{\text{theoretical}}$: 2.31)
Sample 1	1	0.91±0.56	0.90±0.26	$t_{\text{experimental}} = 0.91$
Sample 2	1	1.03±0.44	0.95±0.33	$t_{\text{experimental}} = 0.53$
Sample 3	1	1.10±0.46	1.85±0.36	$t_{\text{experimental}} = 1.60$

* Averages of five repeated measurements

Table 5. Selectivity coefficients obtained for GST sensor

Interfering species	ASS-PME
	Log (K_{MPM})
Na ⁺	-3.8
K ⁺	-3.2
NH ₄ ⁺	-2.8
Ca ²⁺	-3.3
Mg ²⁺	-3.7
Cl ⁻	-3.5
NO ₃ ⁻	-4.2
Lactose	-4.8
Glucose	-4.4

Further the repeatability of the results obtained was assessed through analyzing three synthetic standard samples and calculating the RSD%, which were found to be 3.25%. The ruggedness of ASS-PME was assessed through comparing the intra- and inter-day results obtained using the electrode by two analysts in the same laboratory. The RSD% values obtained for neither of tests exceeded 4.3%. Robustness of the ASS-PMEs was obtained under conditions when the pH of the test solution and the laboratory temperature were slightly changed. Under these conditions the GST recovery% was found to be mostly good upon changing these critical parameters (less than 3.2%).

4. CONCLUSIONS

Given the importance of granisetron, as a serotonin type 5-HT₃ receptor antagonist, used for preventing chemotherapy-induced emesis, an all solid state polymeric membrane electrode (ASS-PME) was devised for this analyte using an ion-pair complex (IPC). To build the electrode an IPC-based polymeric membrane was prepared and used in construction of the sensor and based on the evaluations the optimal composition was found to be one containing 8% GST-tetrakis (p-chlorophenyl) borate, 56% of dibutyl phthalate, 31% of poly(vinyl chloride), 3% of an ionic liquid and 2% of KpCITPB. The all solid state element of the device was also prepared using a conductive composite of graphite, MWCNTs, and epoxy resin coated on a copper wire. The ASS-PME was eventually prepared through coating the PVC membrane on the surface of the solid-state transducer. The resulting electrode had a Nernstian slope of 58.1 ± 0.2 mV/decade over a rather wide concentration window of 1.0×10^{-6} to 1.0×10^{-2} M. The application of the ASS-PME was validated and it was found to be applicable in the quality control analysis of granisetron hydrochloride in some pharmaceutical formulations.

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REFERENCES

- [1] M.V. Tabona, Eur. J. Cancer, 26 (1990) Suppl. 1.
- [2] M. Aapro, Oncologist, 9 (2004) 673.
- [3] C.T. Huang, K.C. Chen, C.F. Chen and T.H. Tsai, J. Chromatogr. B, 716 (1998) 251.
- [4] A. A. Heda, J. M. Kathiriya, D. D. Gadade and P. K. Puranik, Indian J. Pharm. Sci., 73 (2011) 696.
- [5] V.K. Boppana, C. Miller-Stein and W.H. Schaefer, J. Chromatogr. B, 678 (1996) 227.
- [6] B.R. Capacio, C.E. Byers, T.K. Jackson and R.L. Matthews, J. Anal. Toxicol., 17 (1993) 151.
- [7] S.V. Venkata Rao, G. Ramu, N.V.N Malleswara Rao and C. Rambabu, Int. J. Pharm. Tech. Res. 4 (2012) 1508.
- [8] M. R. Ganjali, F. Aboufazeli, F. Faridbod, S. Riahi and P. Norouzi, Chim. Oggi 28 (2010) 4.
- [9] F. Faridbod, F. Mizani, M. R. Ganjali, and P. Norouzi, Int. J. Electrochem. Sci. 8 (2013) 10461.
- [10] M. R. Ganjali, T. Razavi, F. Faridbod, S. Riahi, and P. Norouzi, Curr. Pharm. Anal. 5 (2009) 28.

- [11] M. R. Ganjali, B. Larijani, F. Faridbod and P. Norouzi, *Int. J. Electrochem. Sci.* 8 (2013) 10487.
- [12] F. Faridbod, M. R. Ganjali and P. Norouzi, *Int. J. Electrochem. Sci.* 8 (2013) 6107.
- [13] H.A. Zamani, M. Nekoei, M. Mohammadhosseini, and M.R. Ganjali, *Mater. Sci. Eng. C*, 30 (2010) 480.
- [14] M. Javanbakht, S. E. Fard, A. Mohammadi, M. Abdouss, M. R. Ganjali, P. Norouzi, and L. Safaraliee, *Anal. Chim. Acta*, 612 (2008) 65.
- [15] F. Faridbod, M. R. Ganjali, B. Larijani, P. Norouzi, S. Riahi and F. S. Mirnaghi, *Sensors* 7 (2007) 3119.
- [16] M. R. Ganjali, A. Daftari, P. Nourozi, and M. Salavati-Niasari, *Anal. Lett.* 36 (2003) 1511.
- [17] H. A. Zamani, G. Rajabzadeh, M. R. Ganjali and S. M. Khatami, *Electroanalysis* 17 (2005) 2260.
- [18] M. R. Ganjali, A. Ghafarloo, F. Faridbod and P. Norouzi, *Int. J. Electrochem. Sci.* 7 (2012) 3706.
- [19] H. A. Zamani, M. Rohani, A. Zangeneh-Asadabadi, M. S. Zabihi, M. R. Ganjali and M. Salavati-Niasari, *Mater. Sci. Eng. C* 30 (2010) 917.
- [20] H. A. Zamani, M. R. Ganjali, P. Norouzi and M. Adib, *Sensor Lett.* 5 (2007) 522.
- [21] M. R. Ganjali, L. Naji, T. Poursaberi, M. Shamsipur and S. Haghgoo, *Anal. Chim. Acta* 475 (2003) 59.
- [22] H. A. Zamani, G. Rajabzadeh and M. R. Ganjali, *Sensor Lett.* 7 (2009) 114.
- [23] M. R. Ganjali, J. Ravanshad, M. Hosseini, M. Salavati-Niasari, M. R. Pourjavid and M. R. Baezzat, *Electroanalysis* 16 (2004) 1771.
- [24] M. R. Ganjali, M. Tahami, M. Shamsipur, T. Poursaberi, S. Haghgoo and M. Hosseini, *Electroanalysis* 15 (2003) 1038.
- [25] V.K. Gupta, A.K. Singh, L.K. Kumawat, *Electrochim. Acta*, 95 (2013) 132.
- [26] I. Isildak, *Turk. J. Chem.* 24 (2000) 389.
- [27] I. Isildak, and A. Asan, *Talanta* 48 (1999) 967.
- [28] B. Kemer, and M. Ozdemir, *Turk. J. Chem.* 32 (2008) 521.
- [29] P. Kumar, D. Kim, M. H. Hyun, M. Won, and Y. Shim, *Electroanalysis*, 25 (2013) 1864.
- [30] M.R. Ganjali, F. Faridbod, N. Davarkhah, S.J. Shahtaheri, and P. Norouzi, *Int. J. Environ. Res.* 9 (2015) 333.
- [31] M. R. Ganjali, P. Norouzi, F. S. Mirnaghi, S. Riahi, and F. Faridbod, *IEEE Sensors J.* 7 (2007) 1138.
- [32] C.Z. Lai, M.M. Joyer, M.A. Fierke, N.D. Petkovich, A. Stein, and P. Bühlmann, *J. Solid State Electrochem. Curr. Res. Dev. Sci. Technol.* 13 (2009) 123.
- [33] M. R. Ganjali, Z. Memari, F. Faridbod, and P. Norouzi, *Int. J. Electrochem. Sci.* 3

- (2008) 1169.
- [34] M. R. Ganjali, F. Faridbod, P. Norouzi, Application of ionic liquids in Electrochemical Sensors and Biosensors as a chapter of the international book entitled: "Ionic Liquids, Theory and Applications" (2011), INTECH Publisher.
- [35] A. K. Singh, V. K. Gupta and B. Gupta, *Anal. Chim. Acta*, 1 (2007) 171.
- [36] M. R. Ganjali, M. Rezapour, M. Pirali-Hamedani and H. Rashedi, *Int. J. Electrochem. Sci.* 10 (2015) 6924.
- [37] F. Faridbod, N. Davarkhah and S. Karamdoust, *Int. J. Electrochem. Sci.* 10 (2015) 8308.
- [38] H. A. Zamani, M. R. Ganjali, P. Norouzi, and S. Meghdadi, *Anal. Lett.* 41 (2008) 902.
- [39] H. A. Zamani, G. Rajabzadeh, M. Masrornia, A. Dejbord, M. R. Ganjali, and N. Seifi, *Desalination*, 249 (2009) 560.
- [40] H. A. Zamani, M. R. Ganjali, P. Norouzi, and M. Adib, *Mater. Sci. Eng. C*, 28 (2008) 157.
- [41] M. Hosseini, S. D. Abkenar, M. R. Ganjali and F. Faridbod, *Mater. Sci. Eng. C*, 31 (2011) 428.
- [42] F. Faridbod, T. Jamshidpour and M. R. Ganjali, *Int. J. Electrochem. Sci.* 11 (2016) 7990.
- [43] M. R. Ganjali, P. Norouzi, M. Rezapour, Potentiometric Ion Sensors, in *Encyclopedia of Sensors*, Edited by Craig A. Grimes, Elizabeth C. Dickey, and Michael V. Pishko, Volume 8, page 197-288, American Scientific Publisher (ASP), The Pennsylvania State University, University Park, USA (2005).