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SYNTHESIS, CHARACTERIZATION AND SELECTIVITY OF MOLECULARLY IMPRINTED POLYMER (MIP) GLUCOSE USING POLYEUGENOL AS A FUNCTIONAL POLYMER

Muhammad C. Djunaidi [1,*] , Yayuk Astuti[1]

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ABSTRACT

Research on the synthesis of Molecularly Imprinted Polymer Glucose was undertaken by using polyeugenol as a functional polymer and Polyethylene Glycol Diglycidyl Ether (PEGDE) as a crosslinker agent. Polieugenol generated from eugenol then was tied with glucose template and crosslinked with PEGDE (Polietylene Diglicidil Glycol ether) with a mole ratio of 1:1. Analysis of the results of the polymerization and crosslinking was performed using IR, GPC, NMR and XRD. Optimization of the adsorbent was conducted by varying the template concentration, particle size of the adsorbent and eluent type. Glucose was analysed by 3,5dinitrosalicylic acidmethod. The selectivity of the MIP adsorbent was compared to Non Imprinting Polymer and tested against fructose molecule.A characterization of MIP Glucose consisted of a chemical resistancetest, re-use and selectivity. It is expected that MIP glucose adsorbs glucose more than NIP either in glucose solution or glucose solution mixed with fructose**.**The result was MIP adsobent adsorbed glucose more than NIP but did not adsorb fructose otherwise NIP.The results obtained shows that MIP Glucose was resistant to any kind of organic acids (acetic acid), inorganic acids (HCl, HNO_3) and NaOH. Reuse of MIP Glucose as the adsorbent showsslightdecreased ability to adsorbed glucose when using ethanol, but tended to be stable when using demineralised water as a released solvent. MIP Glucose selectivity was seen in HPLC analysis.

Keywords:MIP Glucose, polyeugenol, fructose, selectivity

INTRODUCTION

Diabetes mellitus (DM) may lead to complications such as cardiovascular disease, kidney failure, blindness, impotence and gangrene. Most people (95%) with diabetes are living with type II diabetes mellitus, a disease resulting from the inability of the pancreas to produce adequate amount of insulin[1,2,3].Treatment of this disease is diet and glucose-lowering drugs in blood glucose levels. Glucose diet can be done in away by providing sugar free glucose for example by selectively adsorb glucose from the sugars sucrose (table sugar), leaving a fructose sugar.

Fructose sugar is safe for people with diabetes. Molecular adsorption MIP (molecularly imprinted polymer) technology offered selective adsorption of glucose.

Hydrogen bonding between amine groups of Poli(allylamine) (PAA) and the hydroxide group of glucose and the addition of crosslinker enables to make effective mold cavity so that it is able to identify/adsorb glucose seven times the fructose, the compound with a structure very similar to glucose[1,2,4,5,6]. Eugenol, a product of our abundant natural material, with its three potential functional groups believed to be able to replace the function of a functional monomer PAA, was even able to increase the selectivity of MIP. Hydrogen bonds between the hydroxide groupsin eugenol and its derivatives with hydrogen atom of glucose compound were believed capable of making more effective the mold cavity and produced MIP adsorbent glucose safer.

EXPERIMENITAL

Materials

methanol, ethanol and chloroform which were technical grade, demineralised waterfrom Bratachem, Chemicals all quality Merck's pure analysis were PEGDE (polyethylene diglycidil Ether), $C_2H_5OC_2H_5$, $BF_3O(C_2H_5)_2$, anhydrous Na_2SO_4, NaOH, HCl, CH_3OH, K-Na tartrat**,** asam 3,5-dinitrosalisilat, D glucose, D fructose, acetic acid, and others were technic quality eg: ethanol, methanol

Instrumentation. UV-Vis (Shimadzu type 1601), **I**nfrared spectrometer (FTIR, Shimadzu Prestige-21), DTA/TGA (BÄHR-Thermoanalyse GmbH-simultaneous Thermal Analyser STA 503), HPLC (Shimadzu), XRD (Shimadzu XRD-8000).

Procedure

Synthesis of polieugenol.

5.8 g of eugenol was put into a 3-neck flask and was added with boron triflourida diethyl ether ($BF_3O(C_2H_5)_2$) as much as 0.25 mL as catalyst for the polymerization reaction. Catalyst was added 4 times every one hour while stirring with a magnetic stirrer. This reaction was allowed to occur at room temperature. The occurance of the reaction was indicated by the change of the solution color from colorless to red. The reaction of polymerization was then allowed to take place continuesly for 12-16 hours after the last addition of catalyst. After which the addidition of 1 mL of methanol into the flask was undertaken to stop the reaction. The resulting gel was

dissolved in chloroform and transferred into a separatingfunnel. Furthermore, it was washed using distilled water for several times until neutral pH was obtained. The resulting organic layer was then moved into a 50 mL erlenmeyer flask.Moreover, anhydrous $Na_2SO_4$was added and followed by decantation. The solvent subsequently was evaporated at 40°C using a rotary evaporator. The dried residue was stored in a desiccator. The solid polymer produced was then weighed and characterized by FT-IR.

Synthesis of MIP Glucose

Grafting of glucose with polyeugenol. 0.5 g of polyeugenol was reacted with glucose with different concentration by stirring for 6 h. The resulting product was then filtered using filter paper and subsequently dried at room temperature.

Crosslinkingpolyeugenol-glucosewith PEGDE as acrosslinker. 0.3 g of polyeugenol-glucose obtained from step A was crosslinked with PEGDE with a mole ratio of 1:1 by heating at of 80-90^oC for 15 minutes using 20 ml of NaOH 1M as catalyst. The product was then neutralized by wahing with distilled water and dried in an oven at 115^oC for 6 h. The final material produced in this method was the Polieugenol-glucose-PEGDE

Elutingglucose from Polieugenol-glucose-PEGDE using an eluent. 0.2 g of Polieugenol-glucose-PEGDE synthesized in step B was eluted using an eluting solvent for 24 h. Glucose had been eluted during this process and MIP glucose was produced.

Synthesis of Non Imprinting Polymer (NIP).

NIP was synthesized using the same way of Glucose MIP synthesis, except there was no glucose grafting undertaken in the earliest stage.

Characteristic of MIP glucose adsorbent. Characterization of MIP glucose was done using FTIR, TGA/DTA, SEM and XRD.

Adsorption of glucose.

50 mg of MIP glucose was contacted with 3000 ppm of glucose. The performance of glucose MIP was evaluated using different glucose concentration, different solvent and particle size.Glucose was characterized by UV-Vis using 3,5 dinitrosalicylic acidas the complexing agent and analyzed with UV at 540 nm.

Making DNS Reagents

30 mL of distilled water was added with 0.5 g of NaOH and 9.1 g of K-Na tartrate, stirring until dissolved. The mixture was then added to a solution of 0.5 g of the DNS (3,5-dinitrosalicylic acid)

little by little while continuing stirring, then added 0.025 g of sodium sulfite and 0.1 g of phenol, and the mixture was stirred continuesly until homogeneous mixture was achieved. This reagent was then stored in a dark container.

Determination of Glucose (and other reducing sugars) concentration with DNS reagent.

The test tube was added 500 mL of glucose standard solution with a certain concentration variations. Each standard solution was added 50 mL 3,5-dinitrosalicylic acid(DNSA) and 950 mL of distilled water. The solution then was stirred with a vortex for 1 min and heated 10 minutes at 100 °C and followed by cooling until it reached room temperature, then centrifuged for 3 minutes at a speed of 9,500 × g to obtain the supernatant brownish yellow. The supernatant from each glucose standard solution absorbance was measured using UV-Vis spectrometer at λ540.

Determination of Glucose and Fructose concentrationsin Mixture solution using a HPLC instrument.

Preparation of sample

1. Sample aliquot was filtered with millex 0,45 uM and then diluted 50 x by double-distilled water. The sample aliquot was then ready to inject to HPLC as many as 40 µL.
2. Preparation of Sugar (Glucose and Fructose in Mixture) Standard
   - Glucose and Fructose standardswere prepared with concentration of 500, 1000 and 1500 mg/L in double-distilled waterand take 40µ andInject to HPLC
3. The HPLC instrument condition

   Colomn: metacarb 87ºC

   Eluent: H_2O

   Flow Velocity : 0.6 ml/min

   Temperature: 85°C. Detector: RID.

Reusable (DNS Analysis)

10 mL of glucose 300 ppm was adsorbed by 0,05 g of MIP Glucose. Glucose adsorbed was leached from adsorbent by ethanol and distilled water. This adsorption process was repeated for 10 times. Analysis of DNS reagent by UV-Vis was used to measure glucose which was not adsorbed.

Chemical Resistance Test for MIP adsorbent.

Chemical Resistance Test for MIP adsorbent was undertaken by immersing MIP adsorbent in variation of solvents that were demineralised water, ethanol (10%), methanol (10%), acetic acid, and some inorganic solvents such as HCl, HNO_3 and NaOH with concentration of 0.5 M each. After immersing in variation of solvents,the MIP adsorbent was analysed using FTIR.

Selectivity Test. 300 ppm of glucose and 300 ppm of fructose wereadded in solution and adsorbed by MIP glucose and NIP and then analysed by HPLC instrument.

Hydrolysis. Hydrolysis of sugar was conducted by diluting a spoon of sugar in 250 mL distilled water and added a piece of lemon fruits and let them hydrolyzed into glucose and fructose for several days. The glucose and fructose concentrations as a result of hydrolysiswere measured using the HPLC instrument. Sample aliquot was stored in a refrigerator until ready for being measured.

RESULTS AND DISCUSSION

Characterization of MIP Glucose.

As we can see in Figure 1, role of –OH group in 3500-3600 cm^{-1} is very important. Polyeugenol-glucose spectrum that indicatedspectrum of polyeugenol after adsorbing glucose compound showed increase in OH- vibration mode[7],but there are decreasing in intensity of OH peak after crosslinking with PEGDE (polyeugenol-glucose-PEGDE). After releasing glucose by ethanol to form MIP Glucose(MIP Glu) there areslighty increasing of OH vibration modesindicating the presence of free OH groups increase. OH groups involved in the creating of MIP were reported by Djunaidi et al (2015)[7,8,9].

FTIR.

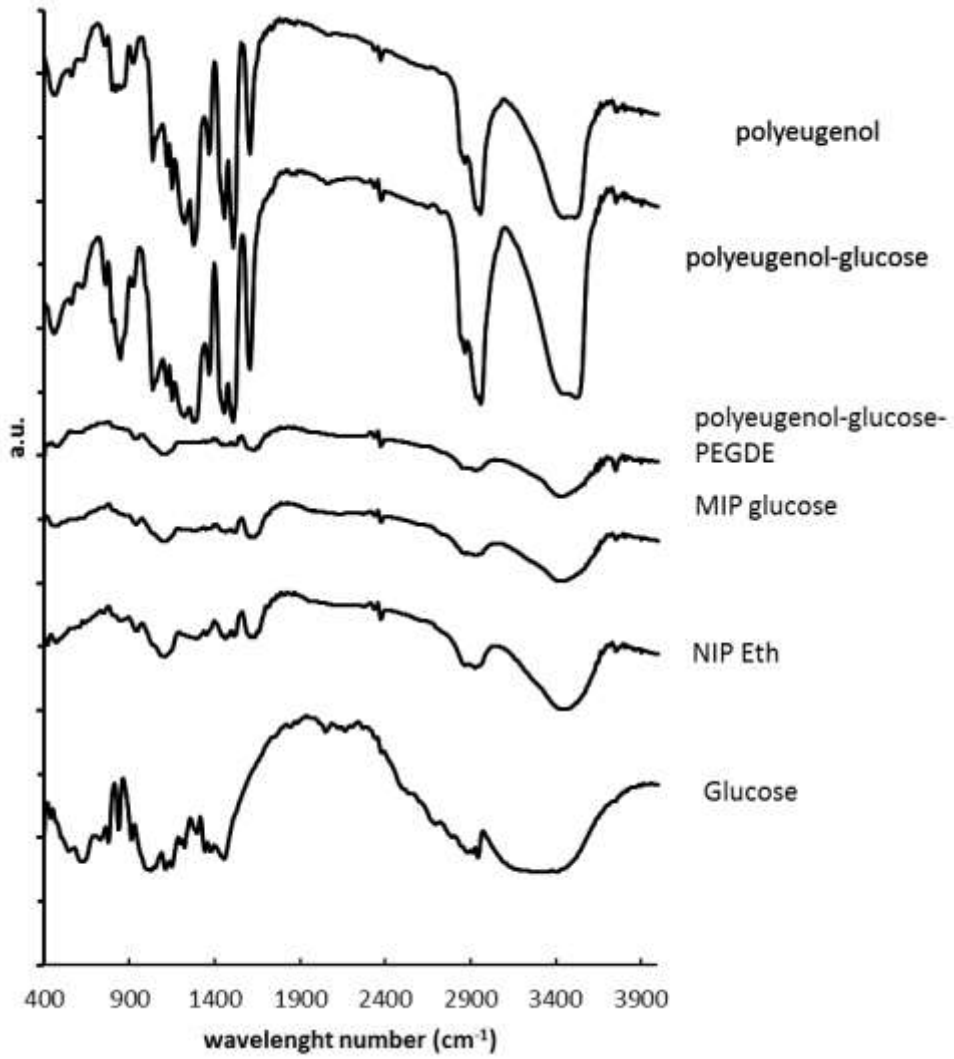


Figure 1. FTIR spectra of various adsorbents and glucose.

XRD.

Figure 2 shows X-ray diffractograms of various adsorbents indicating the bulkier polymer the smaller the cristallinity. MIP-Glu-PEGDE (MIP binding Glucose template and crosslinked by PEGDE) is the bulkier polymer[10] otherwise polyeugenol is the most simple polymer so that it has opposite appearance after being analysed using theXRD instrument.

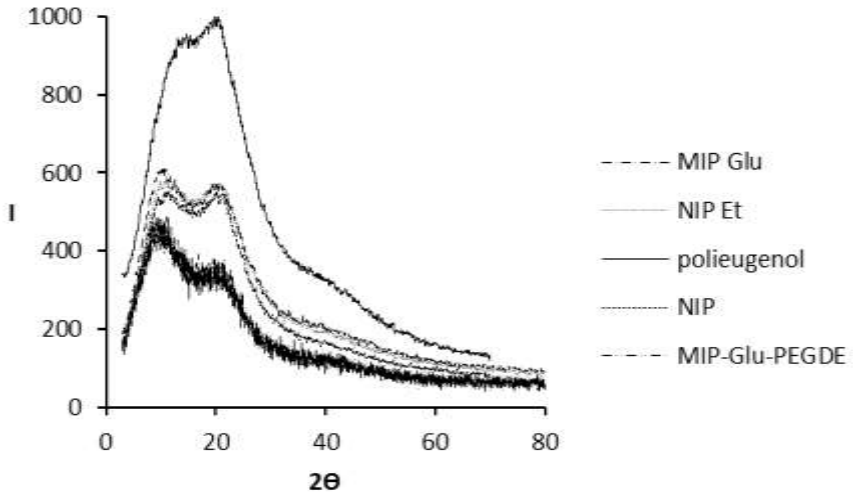
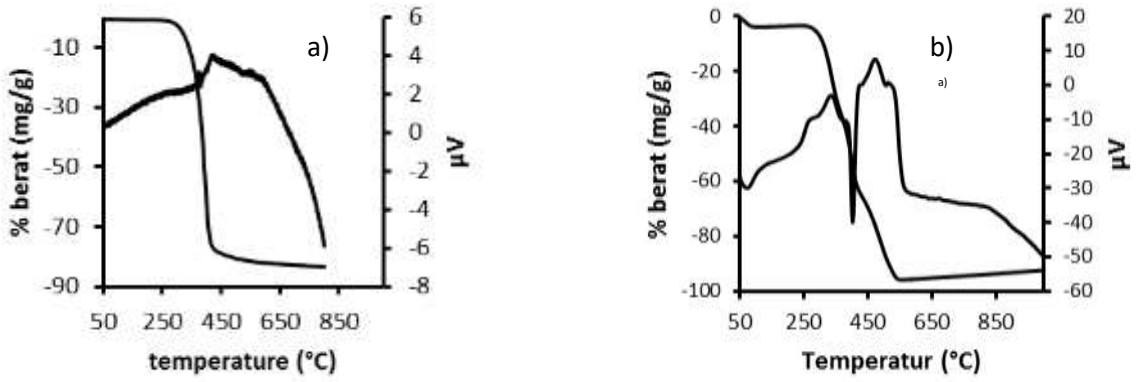


Fig. 2. X-Ray Diffractogramsof various adsorbents.

TGA/DTA

TheTGA / DTA curveof MIP Glucose (Fig. 3b) showsthe sharp losses of weightat temperature of 400 °Cwhich indicated an empty cavity in the adsorbent and free from Glucose. This did not occur in the NIP (Fig. 3a) and NIP Eth (Fig. 3b).

SEM Analysis



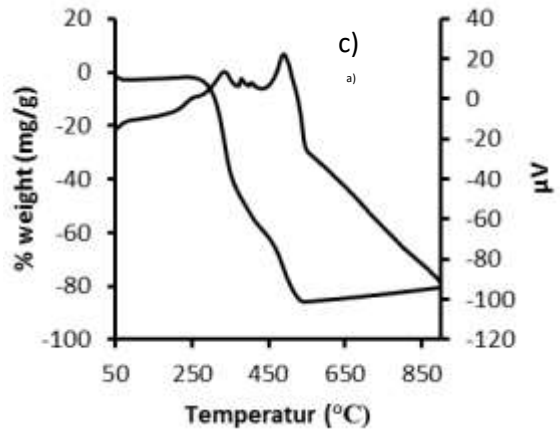


Fig. 3 TGA/DTA Curves of a)NIP, b) MIP Glucose, and c) NIP Ethanol

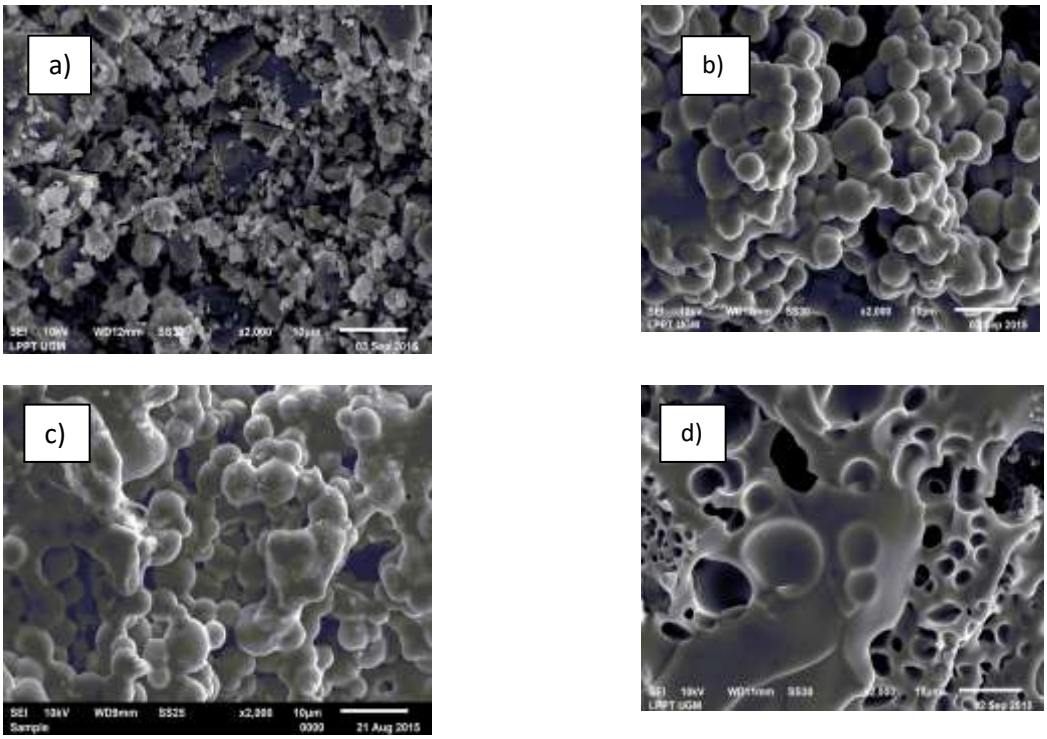


Fig. 4 SEM Images of a) polyeugenol, b) NIP, c) NIP Ethanol and d) MIP Glucose

As seen in the Figure 4, MIP Glucose (Fig. 4d) has relatively larger pores than the other adsorbents. This wasas a result of the empty cavity created after the template was removed using ethanol solvent.

Glucose analysis using DSN

Analysis using DSN provides a standard curve by regression close to 1 as shown in Fig. 5.It indicates that this method was a good method for glucose analysis.Based on Fig. 5, statistically, the limit detection of glucose measurement using DNS method is 0.072 mg/L.

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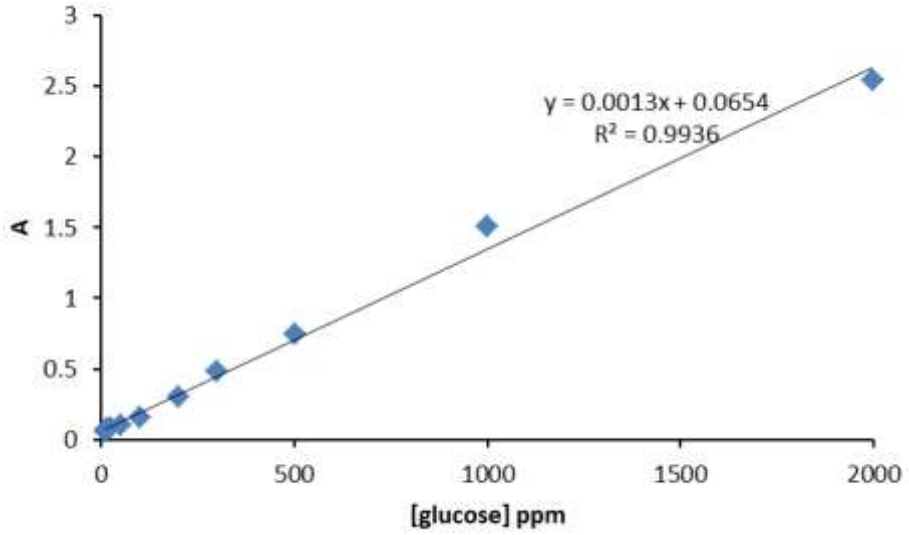

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Figure 5. Calibration curve of measurement glucose in various concentrations using reagent DSN

3.2. Glucose MIP optimalization.

3.2.1. Variations in the concentration of the template.

The concentrations of glucose template were varied at 3000, 7500, 15000 and 10000 ppm.

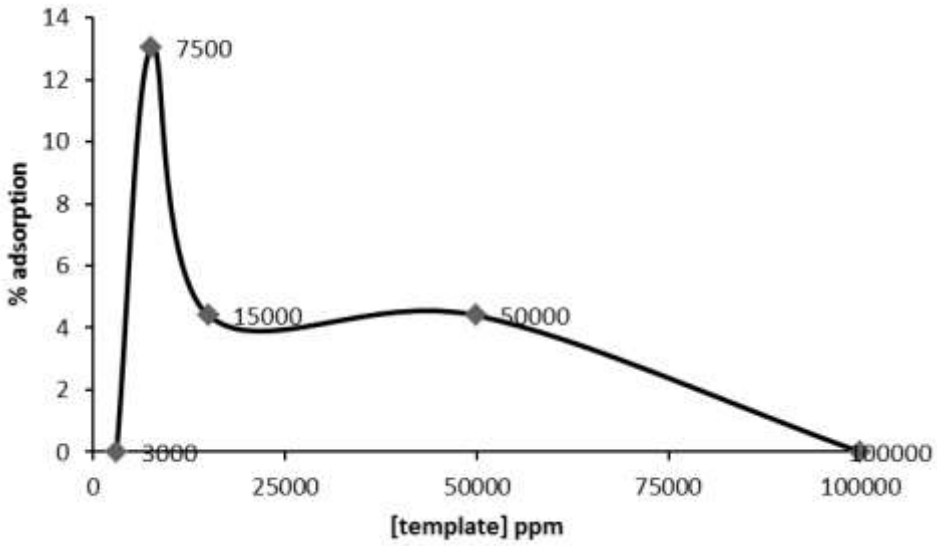

Figure: 6. Curve of variation concentrations of glucosetemplate

Figure 6 shows that the saturated adsorption initially increased with increasing concentration of glucose template, this happened because the number of mold cavities (imprinted cavities) in the MIP increased if the amount of glucose increased, so the amount of saturated adsorption increased MIP[8]. Template of 3000 ppm glucose caused no % glucose adsorption and resulted in NIP-like properties which did not adsorb glucose (Table 3).

After passing the glucose concentration of 7500 ppm template, MIP adsorption amount decreased. This shows that at concentrations of 7500 ppm glucose template, the maximum concentration of the mold cavity has been formed over the mold, so a number of mold cavities were reduced even though the concentration of glucose templates increased. Adsorption became fewer as much glucose "stuck" in the resin and could not be released by demineralised water. Furthermore, MIP with template glucose concentration of 7500 ppm was used for subsequent experiments.

3.2.2. Variation of eluent templates.

To improve the performance of the MIP, varying the eluent templates was undertaken[12]. Types of eluents were water, ethanol and methanol. The results were analysed on glucose adsorption with concentration of 300 and 100 ppm.The resulta can be seen in Figure 7.

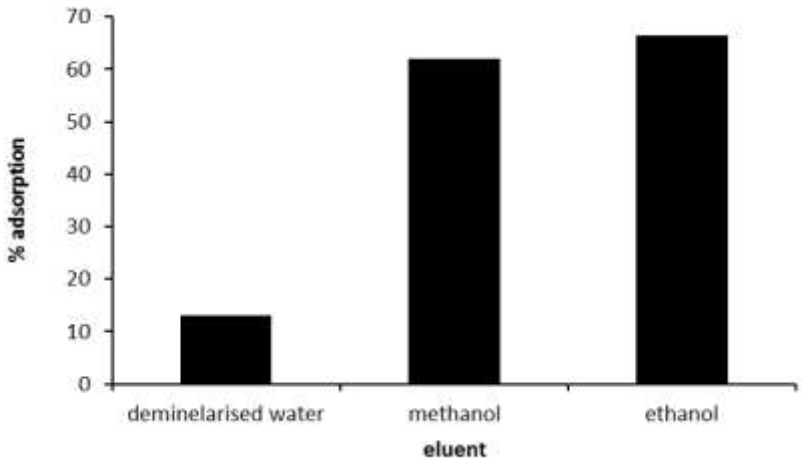

Figure 7. Variation of eluents for the adsorption of 300 ppm glucose

Figure 7 shows that ethanol eluent provided optimum percentageof adsorption, slightly better than methanol. Similar result was shown on the adsorption of 100 ppm glucose, as presented in Figure 8.

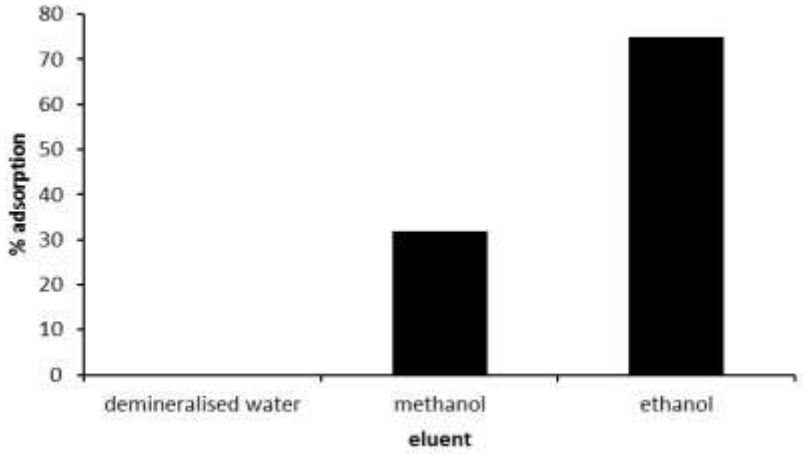

Figure 8. Variation of the eluents for the adsorption of 100 ppm glucose

Figure 8 shows the ethanol was much better than methanol in the elution of glucose. The eluent was used to washing off glucose to form MIP Glucose. These results were used for subsequent works.

Particle Size Variation of MIP

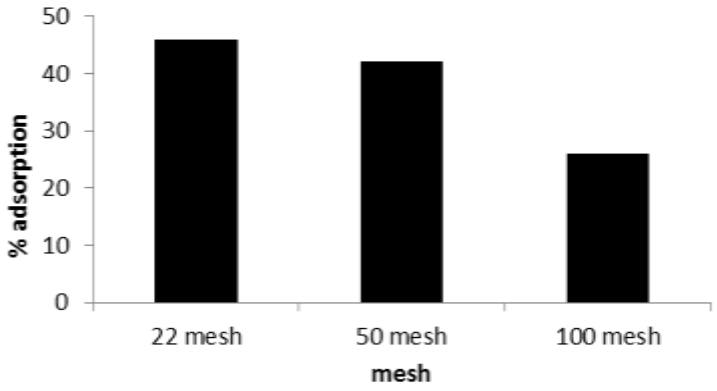

Figure 9. Variation of the particle size of MIP for the adsorption of 300 ppm glucose

Figure 9 shows that the smaller the particle size the smaller the adsorption percentage. It likely occureddue to the damage of the imprinting glucose“space” when being grinded into smaller size.

3.3. Adsorption Kinetics

Adsorption kinetics was studied by modeling the data into pseudo first-order kinetics equation (Lagergren) and pseudo-second order kinetics equation (Ho). Pseudo first-order kinetics equation is formulated as:

$$\ln(q_e - q_t) = \ln(q_e) - k_1 \, t \qquad (1)$$

in which q_e and q_t are the sorption capacity at equilibrium and at time t (mmol g^{-1}) and k_1 is a pseudo first order rate constant 1 (min^{-1}).

Meanwhile, the equation of pseudo-second order kinetic is formulated by:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} \, t \qquad (2)$$

in which k_2 is a pseudo second order constant(g $mmol^{-1}$ min^{-1}).

Table 1. Kinetic parameters for Glucose adsorption onto MIP

Adsorbent	Parameters					
	Pseudo-order 1			Pseudo-order 2		
	q_{e1} (mg g^{-1})	k_1 (L min^{-1})	R^2	q_{e2} (mg g^{-1})	k_2 (g mg^{-1} min^{-1})	R^2
MIP Glucose	0,68	-0,00028	0,1903	47,619	0,000228	0,9822

Parameters of pseudo first order adsorption kinetics and pseudo second order for the sorption of Glucose onto MIP are shown in Table 1. Adsorption kinetics of Glucose onto MIP followed pseudo second order kinetics based oncorrelation coefficient value (R^2). R^2 for pseudo second order kinetics is higher than R^2 for pseudo first order kinetics. Pseudo second order kinetics required that the adsorption process is controlled by chemical bonding between adsorbent and adsorbate especially involving hidrogen bond between hydroxil groups of glucose and atom hidrogen from polyeugenol or and PEGDE.

3.4. Isoterm Adsorption

Several models have been published to describe the adsorption isotherms. Freundlich and Langmuir adsorption isotherms are two types of models which are most often used as models of adsorption in solution.

Equation of Freundlich adsorption isotherm is an empirical equation used for adsorption on heterogeneous surfaces[8]. This equation is formulated as:

$$\log m = \log K_f + \frac{1}{n}\log C_e \quad (3)$$

in which m is the number of metal ions adsorbed (mmol g^{-1}), Kf (L mol^{-1}) is the adsorption distribution coefficient related to Freundlich adsorption capacity, and n is the Freundlich constant indicating heterogeneity of the surface.

Langmuir adsorption isotherm equation is based on the assumption that adsorption process occurs homogeneously and often applied for a single layer adsorption. Langmuir equation is formulated as:

$$\frac{C_e}{q_e} = \frac{1}{bK} + \frac{1}{b} C_e \quad (4)$$

in which q_e is the amount of adsorbate per unit weight of adsorbent at equilibrium (mmol g^{-1}), C_e is the adsorbate concentration in the aqueous phase at equilibrium (mmol L^{-1}), b is the Langmuir adsorption capacity (mmol g^{-1}), K (L mol^{-1}) is the Langmuir adsorption equilibrium constant that can be used to determine the adsorption energy.

Table 2. Langmuir and Freundlich isotherm constants for Glucose adsorption at solution at solution pH value of 3 and 25°C

Adsorbent	Langmuir isotherm parameters					Freunlich isotherm parameters		
	b (mg/g)	K		R^2	ΔG (kJ/mol)	KF (mg/g)	n	R^2
		(L/mg)	(L/mol)x10^4					
MIP Glu Et	38.332	0.000298	0.000373	0.996	-42.380	1.2358	1.903	0.9754

Table 2 shows the parameters of Freundlich and Langmuir isotherm adsorptions. Adsorption of Glucose on MIP was in agreement with the Langmuir isotherm adsorption with R^2= 0.9996. The adsorption capacity of Glucose on MIP was 38.332 mg/g.The adsorption capacity of 38.332 mg/g is in the range of other researchers[1,2,4,11].

The thermodynamic parameter for the adsorption process such as free energy (ΔG^0) can be calculated from Langmuir equilibrium constant using equation[8,9], $\Delta G^0 = -RT \ln K$[7]in which R is the general gas constant (8.314 J K^{-1} $mole^{-1}$), T (K) is the temperature. Free energiesof physisorption, of the physisorption together with chemisorptionand of chemisorption itselfarerespectively lower than -20 kJ mol^{-1}, at the range of -20 to - 80 kJ mol^{-1} and at range of -80 to - 400 kJ mol^{-19}. In Table 2, ΔG^0 value for adsorption of Glucose on MIP was -42,38 kJ mol^{-1}; thus this adsorption involved physisorption and chemisorption simultaneously.

3.5. Adsorption Selectivity.

The adsorption selectivitywas determined by adding 50 mg of adsorbents (MIP and NIP Et in different chamber) to 10 mL of solution containing 200, 300 and 500 ppm glucose. The adsorption was conducted in batch system equipped with a magnetic stirrer.The result can be seen in Figure 10.

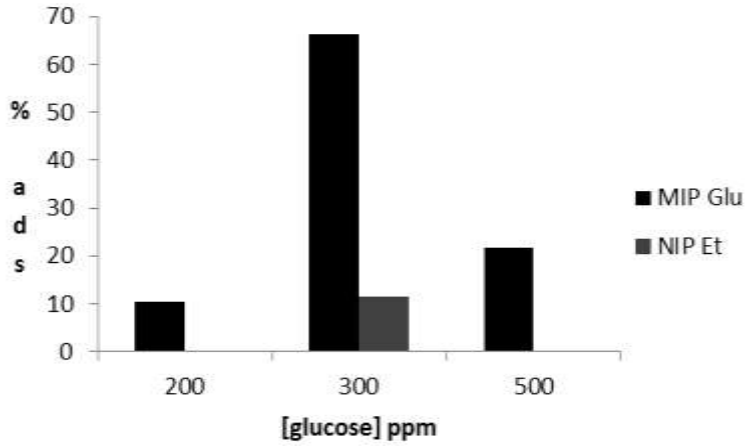

Figure 10. Adsorption percentage of MIP compared to NIP Et

Figure 10 shows that MIP Glucose adsorbed glucose more than NIP, selective pores for Glucose in MIP contributed on this phenomenon. Selectivity of MIP towards glucose (structure of glucose as seen in Figure 11) was proved because 300 ppm fructose was not adsorbed (Table 3) (structure of fructose as seen in Figure 12), a compound that has very similar structure with glucose.

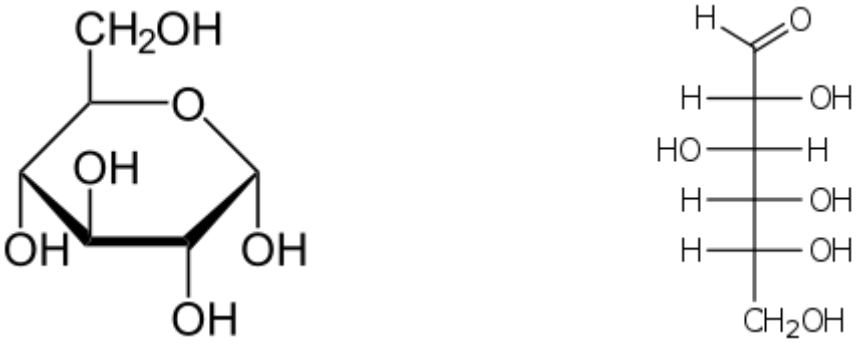

Figure 11. Molecular structure of Glucose.

Figure 12. Molecular structure of Fructose.

Table 3. Selectivity of MIP on glucose and fructose adsorption compared to NIP

Materials	% adsorption	
	Glucose 300 ppm	Fructose 300 ppm
MIP Glucose	66	0
NIP Et	11,58	11,58

.

Table 3 shows that MIP did not adsorbed fructose, otherwise NIP adsorbed fructose. NIP just adsorbed a little amount of glucose, contrary with MIP.

Chemical Resistance Test of MIP Glucose.

Chemical Resistance Test for MIP adsorbent was conducted by immersing MIP adsorbent into variation of solvents both inorganic acids and organic solvents. The adsorbent MIP after immersed by solvents was tested by FTIR.

Inorganic Acids

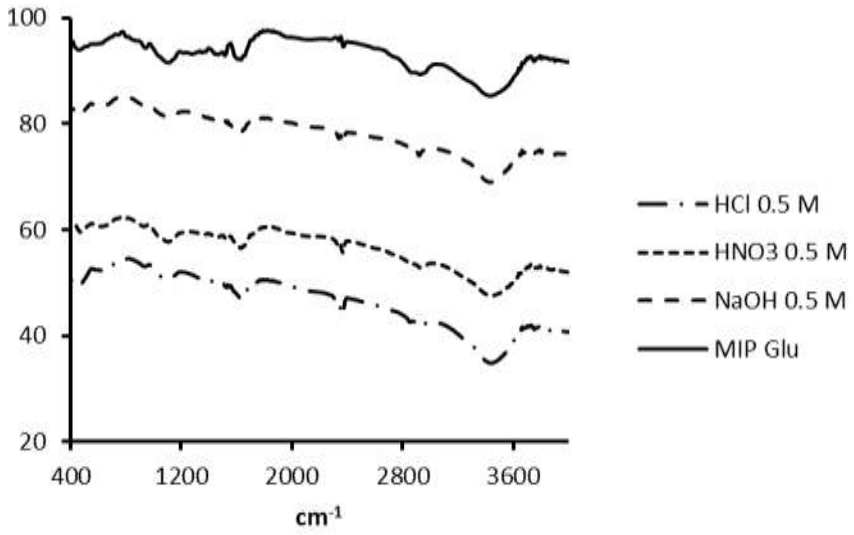

Fig. 13 FTIR spectra of MIP Glucose after immersing in inorganic acids

Organic Solvents.

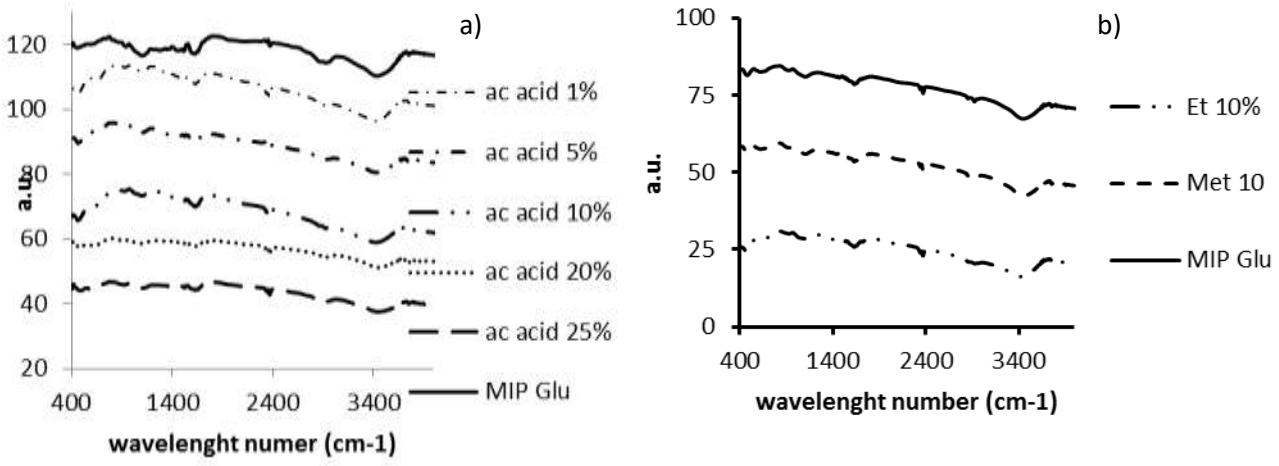

Figure14 FTIR spectra of MIP Glucose after immersing in a) acetic acid b) ethanol (10%) and methanol (10%)

As seen in Figures 13 and 14,there are not any new spectra appeared when compared to MIP Glucose, this indicates a good resistance to various inorganic as well as organic solvents. Especially for the acetic acid solvent MIP showed the chemical resistance below 20 %; above 20 % there was a slight decomposition of Glucose MIP. This can be seen from the decline in the intensity of the IR absorption.

Reusable of MIP Glucose

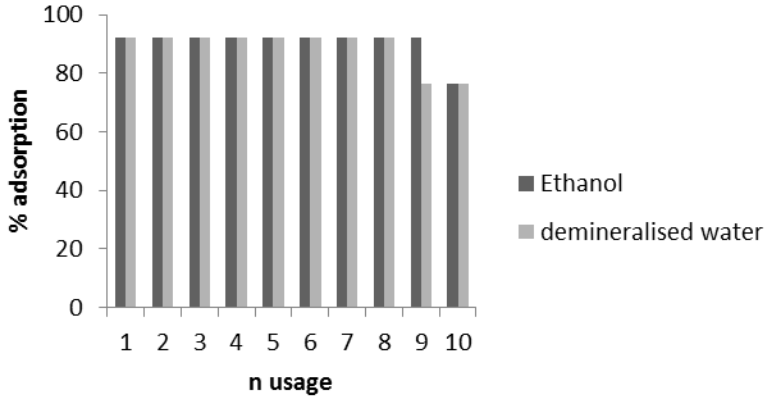

Figure.15 Reusable of MIP Glucose

As seen in Figure 15, the use of both desorption solvents(demineralised water and ethanol) showed a good reusable until eight (8^{th}) usage, 9^{th} and 10^{th}indicatingreduction of MIP ability to adsorb glucose although not too large.

Selectivity in Mixture Solution of Glucose and Fructose

Selectivity of MIP in solution can be undertaken by comparing adsorption percentage of MIP towards glucose compared to fructose. The result can be seen in Table 4.

Table4.Adsorption percentage of MIP and NIP towards fructose and glucose in simulation mixture solution.

	Fructose		Glucose		Sucrose	Ratio
	ppm	% adsorption by MIP	ppm	% adsorption by MIP	% adsorption by MIP	(Fructose/Glucose) rest
Start	316.54		286.5			1.1
NIP 0.1 g	312.47	1.29	271.2	5.34	0	1.15
NIP 0.05 g	301.72	3.39	255.25	10.91	0	1.18
MIP 0.1 g	294.84	6.86	131.31	54.17	0	2.25
MIP 0.05 g	304.65	3.76	150.87	47.34	0	2.02

As shown in the Table 4,MIP selectivity was good because adsorbedmore glucose than fructose and sucrose. Fructose has a similar chemical structure with glucose and only being distinguished by its functional groups.

Hydrolysis

Fructose can be generated from the hydrolysis of sucrose / table sugars with lemon as a catalyst. An experiment was carried out to know the result of a comparison between hydrolysis with and without the catalyst lemon. The results can be seen in the Table 5.

Table5. Hydrolysis of sucrose/table sugars

Catalist	Repetition	ppm		%		Ratio Fructose/Glucose
		Glucose	Fructose	Glucose	Fructose	
Demineralised	1	-	-	-	-	
water	2	-	-	-	-	
Lemon (3 ds)	1	547.	664.25	1.47	1.66	1.22
	2	631.66	661.51			
Lemon (10	1	446.13	706.49	2.23	3.56	1.59
ds)	2	447.48	715.6			

It can be seen in Table 5 that when lemon catalyst was not used hydrolysis of sucrose into glucose and fructose did not occur. On the other hand, when lemon was used, on the third (3^{rd}) day to 10^{th} hydrolysis processes produced fructose and glucose with ratio in the range of 1:22 to 1:59, the role of acid is very important in this case[13].

The adsorption on the aliquot result of hydrolysis on day 3^{th} using MIP adsorbent led to increasing of ratio of fructose/glucose. This occured since the MIP did not adsorb fructose but only adsorbed glucose. It can be seen in the comparison between ratio of remaining fructose/glucose after MIP adsorption in simulation and hydrolysis solutions that were 2.02 and 1.78, respectively (see Table 6). The lower ratio of remaining fructose/glucose in hydrolysis solution is due to the complexity of this solution.

Table6. Adsorption of glucose as a result of sugar hydrolysis

	Initial Ratio	Ratio After Adsorption by MIP
Lemon (3 ds)	1.22	1.78

CONCLUSION

1. In this work, MIP Glucose was prepared using glucose as an imprinted molecule, polyeugenol as a polymer and PEGDE as a cross-linker.
2. MIP also showed a good resistance to organic solvents and inorganic acids.
3. MIP showed good selectivity towards glucose compared to NIP, and did notadsorb fructose,even in a mixture of simulation solution as well as in the result of hydrolysis.
4. MIP Glucose in this research results are still in the range of previous studies so that they are still potential to develope more.

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