

Sequential liquefaction of *Nicotiana tabacum* stems biomass by crude polyhydric alcohols for the production of polyols and rigid polyurethane foams

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ABSTRACT: In this work, *Nicotiana tabacum* stalks and castor oil-based polyol was synthesized *via* two step process. Preliminarily, stalks were liquefied using acid catalyst to procure glycol-glycoside and the optimized conditions for liquefaction of *N. tabacum* stem's biomass was 150 °C temperature for 180 min time using PTSA as catalyst. Progressively, the glycol-glycoside obtained from the former step was further reacted with castor oil in the presence of lithium hydroxide to get dark brown-colored polyol with hydroxyl value was running in between 200 and 400 I_{OH} . Glycol-glycoside and polyols were characterized by chemical and instrumental methods. Further by employing open-cup method involving the mixing of polyol and isocyanate adducts, the desired poly urethane rigid foam was obtained. The product was tested for their physical, mechanical, thermal, and morphological characteristics, while the thermal conductivity was in the range of 0.013 to 0.017 Kcal/mh °C. The performed study may yield high quality rigid or semi-rigid polyurethane foams that are commonly used as insulation materials. © 2016 Wiley Periodicals, Inc. *J. Appl. Polym. Sci.* **2016**, 133, 43974.

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INTRODUCTION

Polyurethane (PU) is one of the most versatile polymer that have been used in a wide range of area. Polyurethanes renders flexible and rigid foams as two predominant applications along with coatings, sealants, elastomers, and adhesives as being other common applications.^{1–4} Currently, the PU industry is heavily petroleum-dependent because of the petroleum-derived two major feedstocks, the polyols and isocyanates. Due to concerns over the depletion of petroleum resources as well as utilization of agricultural waste, extensive research has been concentrated on developing bio-based polyols (biopolyols) and PU products from renewable sources. In some previous studies, polymers obtained from different renewable resources have been reported.^{5,6} However, the utilization of agro-based polymers in other applications have not found an extensive position in the field of polymeric precursors as a replacement of conventional petroleum-based polyols. In the last couple of years, a number of articles based on the biopolyols obtained by liquefaction of various renewable bioresources like agricultural waste,^{7–10} wood,^{11,12} sawdust,¹³ bagasse,¹⁴ and oils^{15,16} have been reported.

In the exploration of other fields to test the applicability of this abundant byproduct, one possible clarification obtained is its conversion to materials with high additional value as well as the

products of industrial interest that can help to increase the economy of the processing plants. In that sense, numerous systems have been investigated in relation to green chemistry for the product development from waste. Moreover, the liquefaction of natural polymeric substrates has been an attractive field of study leading to applicable finished product. The liquefaction of natural polymers and other substrates from biomass is a method that increases the starting material's —OH functionality by moving the hydroxyl groups to the chain end and thus being much more accessible to react. The liquefaction converts these solids, frequently intractable biomass residues, into liquid polyols which is a viscous liquid made up of liquefied —OH containing substrate and propylene oxide homopolymer fraction. The corresponding hydroxypropyl derivatives can be used directly as rheological modifiers, additives, and various other applications.^{15–18} The high reactivity of the liquefied product is attributed to the presence of a large amount of phenolic as well as alcoholic hydroxyl groups. A numerous applicable polymers such as epoxy resins, adhesives, and fuels have been prepared from the produced polyols.

Across the literature, very few studies have been found focusing on the liquefaction of *Nicotiana tabacum* stalk using organic solvents. Glycosylation of biosources with ethylene glycol and the synthesis of polyols have been previously studied and

evaluated for the production of polyols as starting material for the preparation of polyurethanes.^{13,14,17,18} Therefore, the present work is aimed to study the liquefaction of *N. tabacum* stalk using polyethylene glycol (PEG#400) as solvent system. Liquefaction conditions, such as raw material to solvent ratio, solvent type, catalyst concentration, liquefaction temperature, and time have been investigated. The functional group identification of liquefied products was characterized using FT-IR spectroscopy. The hydroxyl groups and acid number, which are important parameters in the preparation of polyurethanes, were also determined for the resulted polyols.^{19,20}

Furthermore, polyurethane foams (PUFs) with peculiar mechanical properties were developed from the liquefied biomass upon optimization of the formulation, as opposed to what is commonly achieved when using other bio-based polyols which generally yield rigid foams. While the thermal stability and thermal conductivity of the PUFs produced are within the values as prescribed for other PUFs derived from renewable resources which are manufactured suitably for thermal insulation. Moreover, the mechanical behavior of biomass-derived PUFs proposed that they can find significant application in the fabrication of viscoelastic foams whose properties can be tuned by changing the percentages of blowing agent and surfactant depending on the application in mind.

In this study, the feasibility of using *N. tabacum* stalk to obtain valuable and low-cost polymeric precursors and its applicability to develop polyurethane foams (PUFs) was studied. For the same, glycolysis of cellulosic material (pretreated *N. tabacum* stalk powder) using ethylene glycol was performed leading to the synthetic polymeric precursors. Further, the synthesized polymeric precursors, the polyols were utilized for the development of PUFs. Foams are microcellular structures, commonly used as insulating material, seat cushion, and automotive seating.²¹ The feasibility to use the prepared precursors from the *N. tabacum* stalk for its application in preparing PUFs is suggested.

EXPERIMENTAL

Materials

N. tabacum stalk was collected from the local farms. *p*-Toluene-sulfonic acid (PTSA), (crystallized before use), dibutyltin dilaurate (DBTDL), sulfuric acid (S. D. Fine-Chem Ltd., Mumbai, INDIA) were used as catalyst, polyethylene glycol (PEG#400) (S. D. Fine-Chem Ltd., Mumbai, INDIA), and acetone (S. D. Fine-Chem Ltd., Mumbai, INDIA) were used as glycolising reagent and solvent, respectively without purification. Double filtered castor oil, having hydroxyl value 165, was obtained from local market. Double distilled water was used as a chemical blowing agent. Toluene diisocyanate (TDI) adduct, containing 13.3 (± 0.4)% free —NCO , was supplied by Gads Fine Chem. Ltd., Ahmedabad, Gujarat, India. Silicon oil, used as surfactant, was supplied by Berger Paints, V. U. Nagar, Gujarat.

Methods

Physicochemical Property. Hydroxyl value and acid value were determined as per the standard methods.²² Nonvolatile matter (NVM) was determined by taking 1 g sample in previously weighed silica crucible which was kept at 120 °C in thermostat

oven for 1 h, then cooled 90 °C before transferring to desiccators. The loss in weight of a sample was converted to percentage, which was attributed to the volatile matter present in the sample. Viscosity of polyols was determined by Brookfield Viscometer (RTV standard, Spindle No. 2 at 100 rpm). Color of polyols was analyzed by Gardner color comparator and the moisture content by Karl-Fisher titration.

Fourier Transforms-Infrared Spectroscopy (FT-IR). The liquefied product as well as prepared polyol were characterized by FT-IR analysis of tablets prepared from 1 mg of sample with 100 mg of KBr, using a Perkin Elmer Spectrum GX FT-IR spectrophotometer. The infrared spectrum was recorded in the 4000 to 500 cm^{-1} range by accumulating 32 scans with the resolution of 4 cm^{-1} .

Gel Permeation Chromatography (GPC). To study the molecular weight of depolymerized product, GPC was performed using Perkin Elmer turbomatrix-40. Tetrahydrofuran (THF) was used as mobile phase at a flow rate of 1 mL min^{-1} .

High-Performance Liquid Chromatography (HPLC). HPLC analysis was done using Perkin Elmer series 2000, with a reverse phase column having the 10 μm pore size. HPLC grade water was used as the mobile phase with a flow rate of 1 mL min^{-1} at 40 °C.

Thermal Conductivity. Thermal conductivity of prepared foam was measured by divided base method. In this method a thin sample plate is sandwiched between two metal roads. The cross-section of sample is the same as the shape of metal roads. Heat is provided from one end of the block. Temperature are measured at given point and its allow us to determine the thermal conductivity.

Thermogravimetric Analysis (TGA). TGA was carried out using Mettler Toledo thermogravimetric analyzer (TGA) model (TGA/STDA 851 e). The weight loss of samples during temperature ranging from 50 °C to 610 °C was measured under nitrogen flow 10 mL min^{-1} with a heating rate of 10 °C min^{-1} .

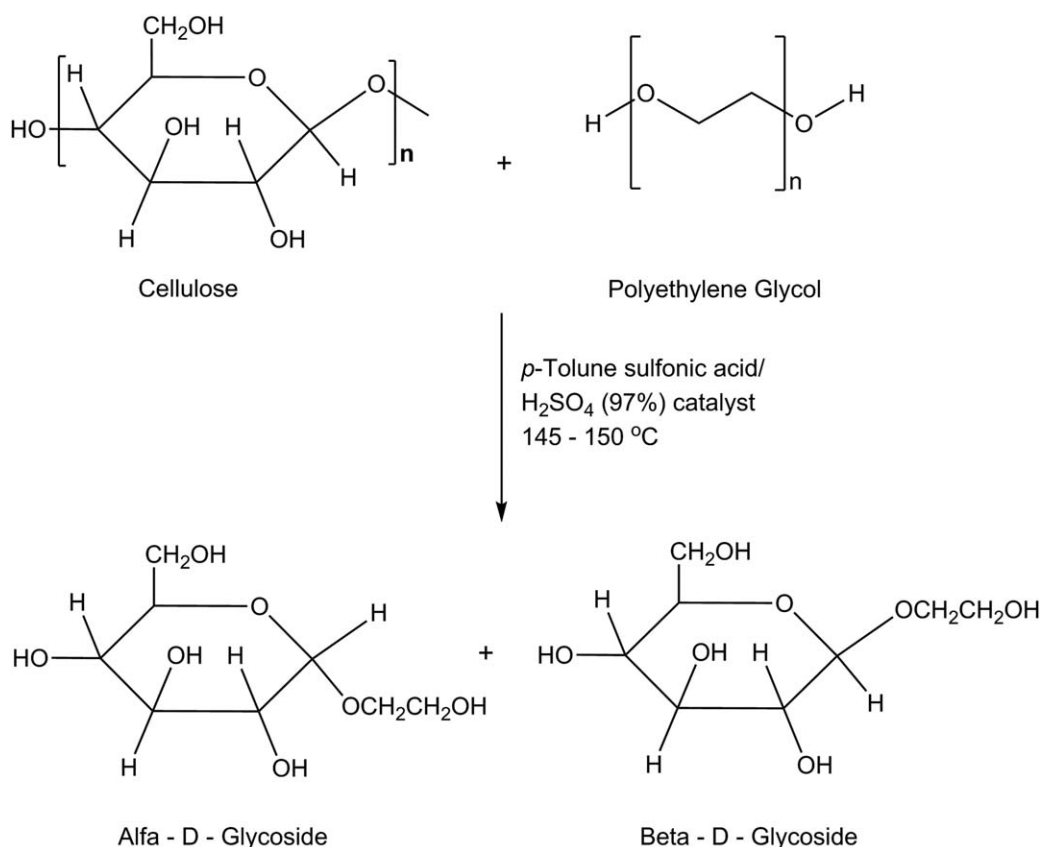
Scanning Electron Microscope (SEM). A study of morphological properties by SEM images of the samples were obtained in a Theophylline Microspheres (FEG-SEM) operating at 5 kV. The samples were placed on a plastic support.

Pretreatment to Cellulosic Waste

N. tabacum stalk was cut into small pieces, dried in the sun for 24 h, and ground up to 18-mesh with the help of roll mill. The resulted powder from the mill was refluxed using H_2SO_4 and NaOH (1.25% M m^{-1}) for 2.5 h, and resulted in the purified form of powder used as base material for value added polymeric material.

Glycolysis of *N. tabacum* Stalks Powder

A three-necked flask equipped with stirrer, nitrogen inlet, a contact thermometer having accuracy of ± 0.5 °C, vacuum arrangement, and reflux condenser was charged with 150 mL of polyethylene glycol along with PTSA 0.5% (w/w) as a catalyst. Trace of moisture was removed by heating the mixture to 85 °C in a nitrogen atmosphere and reduced pressure (125 mmHg). Five grams of purified *N. tabacum* stalks powder was added and the mixture was heated at 145 °C to 150 °C for 3.0 h. The



Scheme 1. Liquefaction of *Nicotiana Tabacum* stems biomass.

reaction mechanism was shown in Scheme 1. The remaining catalyst was neutralized with barium hydroxide, and light brown viscous liquid was extracted from the residue with acetone by vacuum filtration using Whatman filter paper (No. 1). Acetone was distilled under vacuum and unreacted ethylene glycol was distilled off at 150 °C under reduced pressure of 125 mmHg. Thus the obtained product contained α and β -D glycoside.^{20–23} The % conversion of feed to the glycoside and the color of the obtained product was determined, while optimization and results were shown in Tables I and II. The glycoside product thus obtained was used without further purification to synthesize the polyols.

Table I. Optimization of Catalyst for Liquefaction of *Nicotiana Tabacum* Stems Biomass

Catalyst	Temperature (°C)	Time (min)	% Conversion
H ₂ SO ₄	110	90	06
	110	120	07
	190	90	36
PTSA	190	120	44
	110	90	12
	110	120	13
	190	90	69
	190	120	77

In order to find the % conversion of feed to glycoside, residue obtained after glycolysis was washed with acetone until all the glycoside was extracted from the residue and dried in a vacuum oven for 24 h, at 70 °C. The dried residue was stored in a desiccator.

The % conversion (w/w) of feed was calculated according to the following equation.

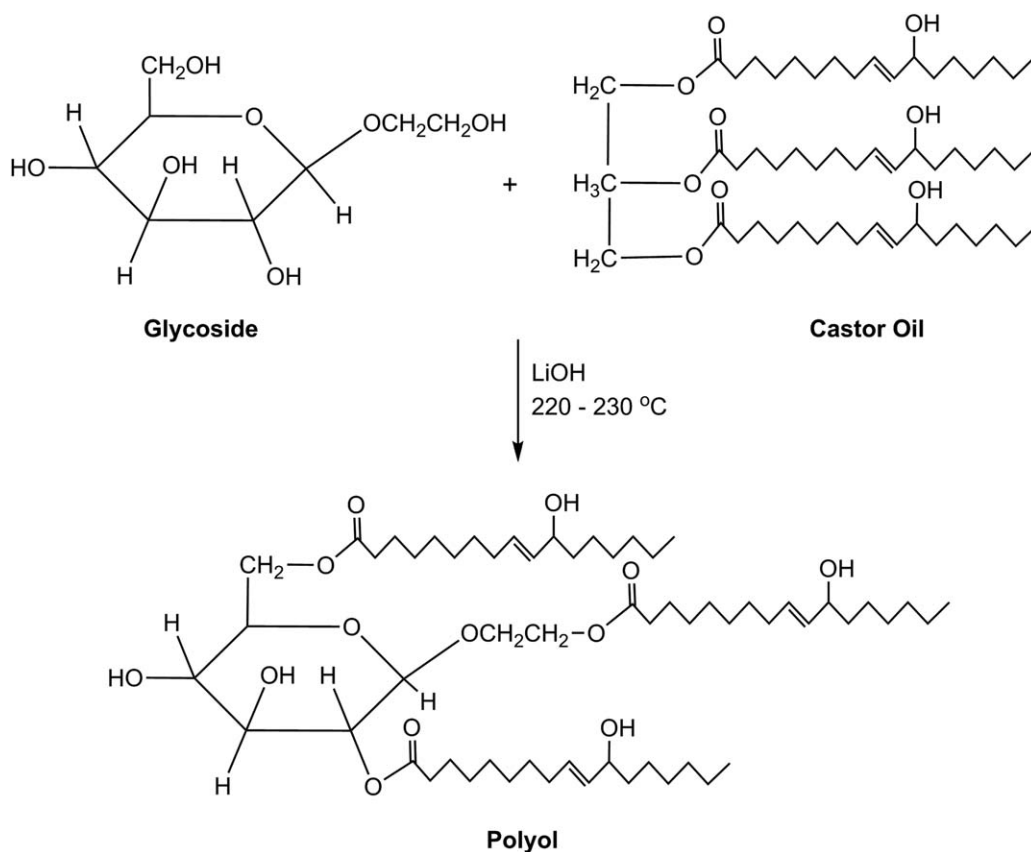
$$\% \text{ Conversion (I)} = \frac{(w_0 - w)}{w} \times 100$$

where W_0 is the weight of the initial dry *N. tabacum* stalk and W is the mass of the residue obtained after the liquefaction.

Synthesis of Polyol

A calculated amount of castor oil and 0.4% (w/w) of lithium hydroxide was taken in 500 mL three-necked flask equipped with a nitrogen inlet, contact thermometer, mechanical stirrer, and vacuum arrangement. The heterogeneous mixture was heated to 80 °C under reduced pressure of 125 mmHg and required amount of glycoside was added to it. The reaction temperature was raised to 220 to 230 °C and the reaction mixture was stirred at this temperature for 1 h. The reaction mechanism was shown in Scheme 2. Then it was cooled to 90 °C and vacuum was released and the obtained polyol was allowed to cool to room temperature. Being hygroscopic in nature, polyol was stored in an airtight container.

The ratio of glycoside to oil was varied to obtain polyol of different hydroxyl values, and the obtained polyols were coded as



Scheme 2. Synthesis of polyols.

CAS-1, CAS-2, and CAS-3. To obtain the required hydroxyl value, greater amount of glycoside was added, which resultantly contributed to decrease in viscosity of polyols (Table III). The synthesized polyols were tested for hydroxyl value, acid value, moisture content, NVMs, viscosity, color, and specific gravity.

Preparation of PUFs

The hydroxyl value was possible to be tailored with the aid of vegetable oil addition. Thus a range of edible/nonedible oil having different hydroxyl value was preferred in polyol synthesis.^{24–30} Polyol with a hydroxyl value of 300 was randomly chosen to prepare the PUF, and the given formulation (Table IV) was used for the preparation of foam. In a dry and clean plastic container, polyol was mixed for 2 min with suitable amount of water, surfactant, and catalyst,^{26–32} then TDI adduct was added and mixed with vigorous stirring at 2000 rpm for 80 s. The mixture was then transferred into an open Teflon mold, previously greased with a silicon mold release agent. The mold was maintained at 55 °C for 50 s, and thus prepared foam was postcured at room temperature for 1 week. Cream time, rising time, and gel time was determined.

RESULTS AND DISCUSSION

The reaction parameters *viz.* temperature, time, and catalyst for glycolysis were optimized on the basis of conversion % calculated from the residue obtained after glycolysis reaction. Glycolysis of cellulose in the *N. tabacum* stalk feed using polyethylene glycol was confirmed by FT-IR spectroscopy and HPLC chro-

matogram. Chemical and instrumental analyses of prepared polyol are done. Polyurethane foam processing parameter cream time, rising time, and gel time were measured and its characterization was done by TGA and morphological study.

Glycolysis of *N. tabacum* Stalk

Optimization of Liquefaction Reaction Methodology. According to literature survey, number of successful attempts have been made to utilize the renewable material via liquefaction process, which revealed that the amount and selection of the catalyst are the dominant parameters affecting the % conversion of liquefaction technique. In concern to the % conversion value the most proficient catalyst was acid catalyst. Acid catalysts such as H₂SO₄, HCl, H₃PO₄, PTSA, CH₃COOH, FeCl₃, etc. have been frequently used in liquefaction of biomass. In reference to this, we were encouraged to practice the liquefaction process for the tobacco stem *i.e.* waste renewable biomass utilizing PTSA and H₂SO₄ as acid catalyst for optimization due to its easy availability and low cost. With the aim of providing economical and easy liquefaction process, we made series of reactions to optimize the parameters mainly catalyst, time, and temperature. In this frame work, we optimized the parameters by dividing into two phases *i.e.* first phase and second phase.

In the first phase, we concentrate on to the selection and optimization of the catalyst. In particular to this, both the catalysts were studied at isothermal and constant time with reference to % conversion as shown in Table I. We found that PTSA was more effective than H₂SO₄, which give higher % conversion.

Table II. Optimization of Temperature and Time using PTSA as Catalyst for Liquefaction of *Nicotiana Tabacum* Stems Biomass

Temperature (°C)	Time (min)	% Conversion
110	30	07
	60	10
	90	12
	120	13
	150	20
	160	21
	180	21
130	30	09
	60	10
	90	15
	120	25
	150	30
	160	30
	180	31
150	30	20
	60	50
	90	75
	120	85
	150	92
	180	94
	210	94
170	30	20
	60	50
	90	75
	120	85
	150	92
	160	70
	180	65
210	64	

In second phase, we focus on to the optimization of temperature and time simultaneously. In particular to this, previously optimized catalyst PTSA was further studied in reference to % conversion with temperature and time, and in this phase, both the parameters were studied by fixing one and altering other, while the results were show in Table II. Observed results revealed that at 150°C temperature maximum value of % conversion was achieved, while after 180 min time % conversion

Table III. Physicochemical Property of Polyols

Sample code	Hydroxyl value	Acid value (mg of KOH/g)	Specific gravity	Viscosity (cP)	% NVM (at 120°C for 1 h)	Color (Gardner)	Moisture (%)
CAS-1	206	2.45	1.212	690	98.7	17	0.6
CAS-2	309	2.06	1.228	320	98.5	18	0.3
CAS-3	404	1.89	1.240	309	98.0	18	0.2

Table IV. Foam Formulation

Polyol	TDI (pphp)	Surfactant (pphp)	Catalyst (pphp)	Blowing agent (pphp)
100	150-255	0.2-10	1-3	0.2-20

was constant and thus the optimized condition for liquefaction of *N. tabacum* stems biomass was 150°C temperature for 180 min time using PTSA as catalyst.

Effect of Reaction Time and Temperature. It was evident from Figure 1 that, at 180 min, maximum conversion (94%) of *N. tabacum* stalk powder feed was achieved. At first, the conversion of the feed was slow but it quickly increased between the period of 30 and 90 min. Half an hour was necessary for swelling and disintegration of the feed, after which the reaction mixture was in homogeneous suspension and the reaction rate increased rapidly. The maximum conversion was obtained at 150 min. The reaction was supervised for 210 min. There was no substantial increase in reaction after 180 min. Further increase in reaction time resulted in the decomposition of the product.

Figure 2 depicts the % conversion of the feed after 180 min at different temperatures enhancement in the conversion of feed with respect to increase in reaction temperature up to 150°C was observed. An impulsive and hurried raise in conversion was noted at 160°C. These results were in agreement with the previous work by Hu *et al.*²⁶ based on soybean straw.

Effect of Catalyst. The PTSA has shown a great impact on the reaction rate as can be seen from the comparative study of catalysis on the glycolysis reaction. The yield was 94% when PTSA was used as compared to 80% when using sulfuric acid. Other disadvantage of using sulfuric acid was lower yield due to decomposition of cellulose in the feed was faster at the reaction temperature, whereas PTSA gave high yield even at higher temperatures. The yield obtained by these catalysts is comparatively good as compared to previous work done by Wang and Chen.³³

Instrumental Analysis of Glycol Glycosides. Glycolysis of cellulose in the *N. tabacum* stalk feed using polyethylene glycol was confirmed by FT-IR spectroscopy. Figure 3 shows the FT-IR spectrum of synthesized glycoside. As suggested in the glycolysis reaction, ethylene group of polyethylene glycol gets attached to the cellulose molecules, breaking the glycoside linkage in polysaccharide. Absence of absorption band at 1175 to 1140 cm⁻¹, which shows the glycoside linkage in polysaccharide, confirmed breaking of this bond. Sharp bands at 1184 and 1042 cm⁻¹ were obtained due to ether (C—O—C) linkage of new formed glycoside, which

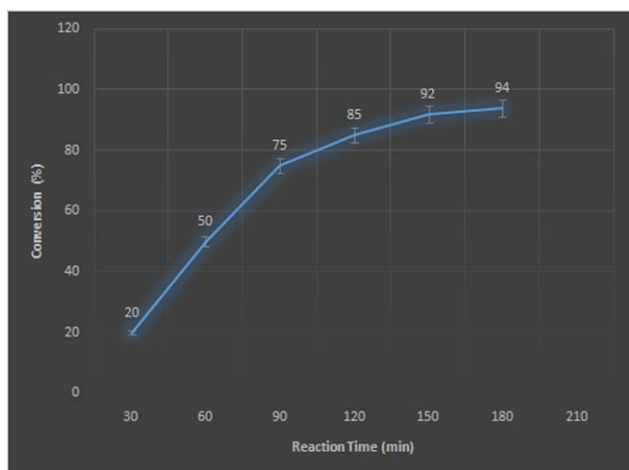


Figure 1. Effect of reaction time on % conversion. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

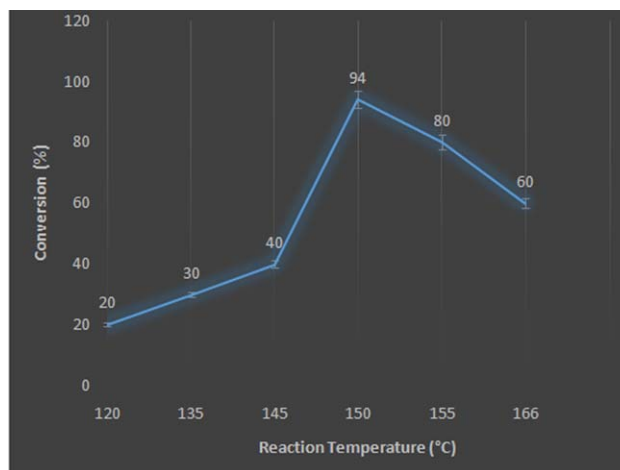


Figure 2. Effect of reaction temperature (°C). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

confirmed the suggested structure. A broad band at 3390 cm^{-1} is due to free hydroxyl groups. Sharp absorption band at 2946 and 2881 cm^{-1} are attributed to alkyl C—H stretching vibrations. Bands at 1648 and 1458 cm^{-1} are due to C=O stretching and C—H deformation, respectively, in cellulose molecule.³⁴

The two isomers of glycoside were confirmed from the HPLC chromatogram of glycoside, which (Figure 4) show two major peaks at retention time of 2.413 min and 4.620 min, which were due to isomers of glycosides. The third minor peak at 1.665 min was due to traces of polyethylene glycol.

Polyols

Chemical Analysis of Polyols. The physicochemical analysis of synthesized polyols was shown in Table III. Three different syn-

thesized polyols were having experimental hydroxyl values, 206, 309, and 404. The acid values were less than 2.5 and specific gravities were in the range of 2.2 to 2.4. Light brownish yellow to brown-colored polyols were obtained having NVM more than 98%. The sudden decrease in viscosity was obtained in another two polyol compared to CAS-1. The long and semicross-linked structures of polyols were the two main factors, which resulted in low viscosity polyols.

It was also found that the content of glycoside in polyols was determined factor for the viscosity of the polyols. As the glycoside content was increased to obtain the higher hydroxyl value of polyol, the viscosity of the resultant polyols decreased. As it is an alcoholysis type of reaction, it decreased the polymerization and only modifies the chemical structure of the oil,

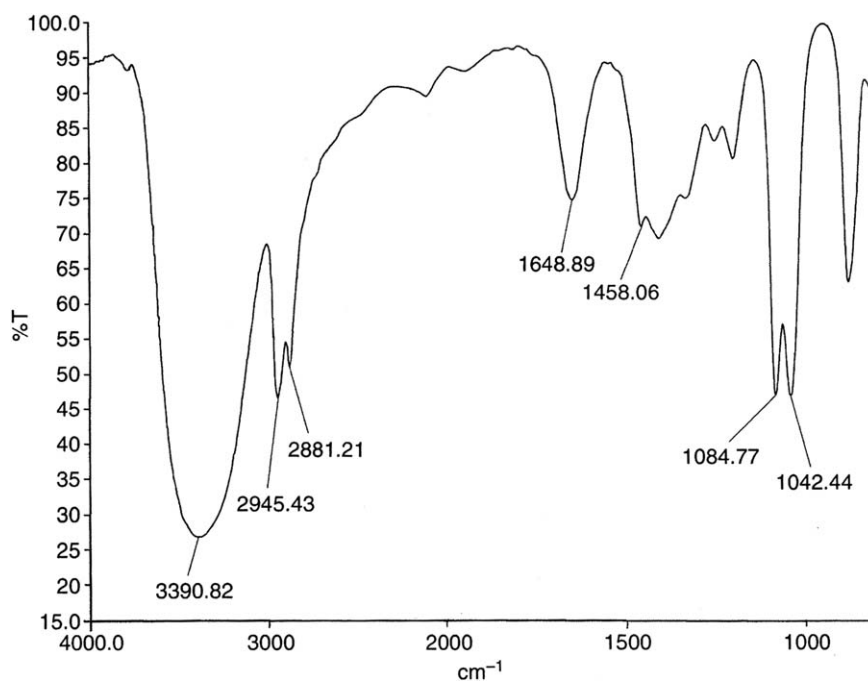


Figure 3. FT-IR spectrum of glycoside.

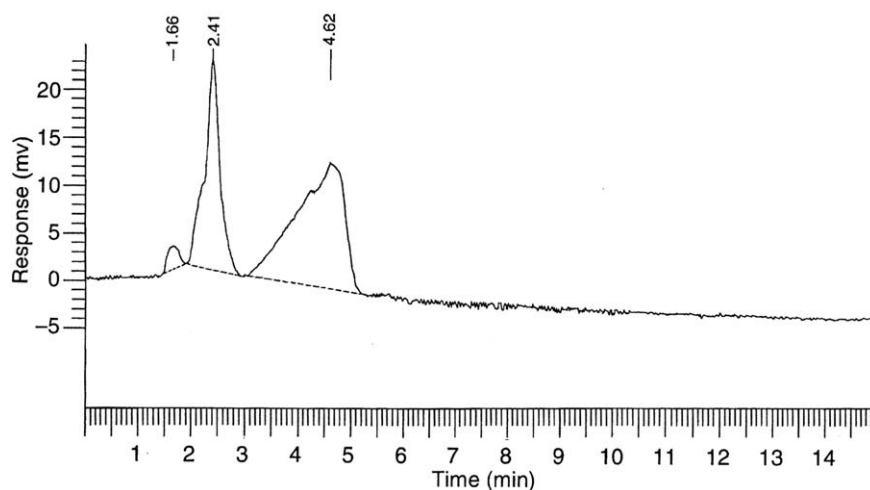


Figure 4. HPLC of glycoside.

resulting in a decrease in viscosity of polyol when greater amounts of glycoside was added.

Instrumental Analysis Polyols. Figure 5 shows FT-IR spectroscopy, in which Spectrum A and Spectrum B shows the characteristic bands of castor oil and prepared polyol, respectively. The band at 3404.59 cm^{-1} is due to free hydroxyl groups become broad in polyol, indicating the rise in hydroxyl content. The band at 1736 cm^{-1} is due to C=O stretching, that is, carbonyl group of ester linkage formed between fatty acid chain and glycoside. It becomes more intense and broad in polyol compared to castor oil, confirms the transesterification of oil with glycoside.³⁴

Gel permeation chromatography of the prepared polyol was performed to study the molecular weight average and polydispersity

of the synthesized polymer precursor. The chromatogram of prepared polyol is displayed in Figure 6 which reveals one peak at retention time 8.840 min corresponding to a number average molecular weight of 1092 g mol^{-1} with a molecular weight of 1291 g mol^{-1} with a polydispersity ratio of 1.183 which indicates polydispersity.

Polyurethane Foam

Processing Parameters and Density. Cream time, rising time, and gel time was measured with error of 1.5 s, which were 30, 50, and 85 s, respectively. The cream time for prepared foams were slightly higher as generally obtained for PUFs because of the use of isocyanates adducts in the formulation in place of pure isocyanate, which was intentionally used to control the reaction.

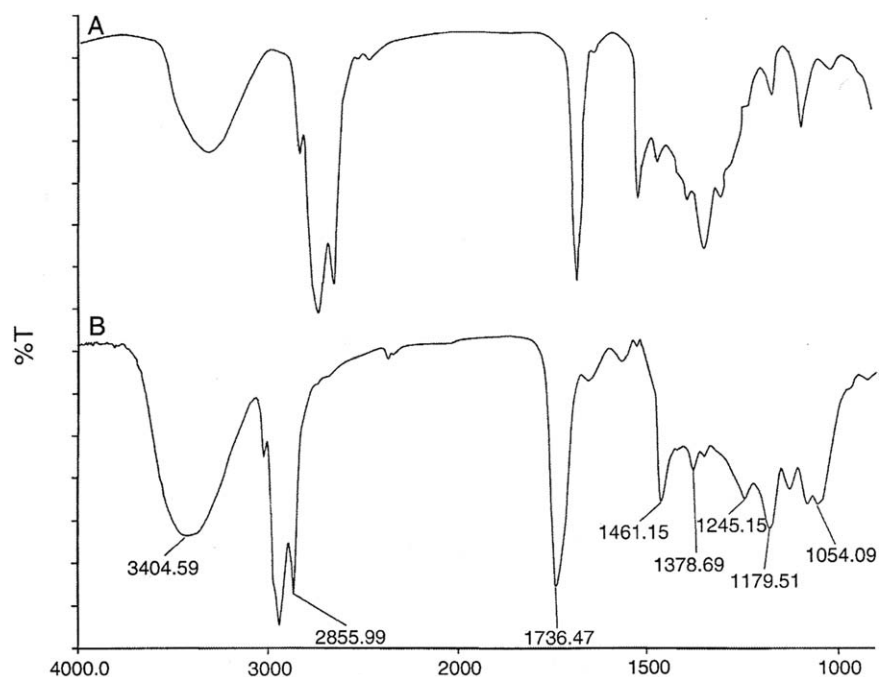


Figure 5. FT-IR spectra of prepared polyol.

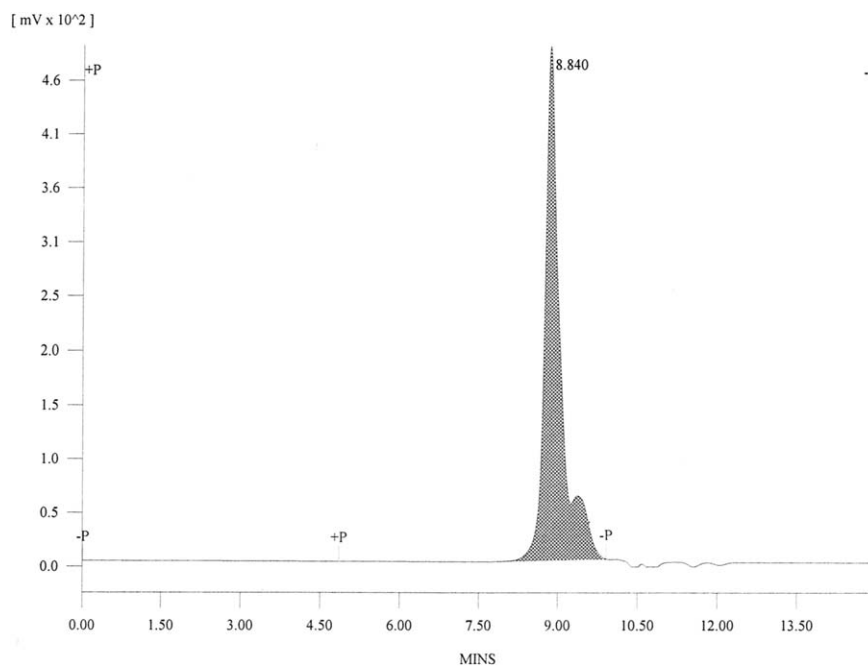


Figure 6. GPC of prepared polyol.

Density of prepared foam was measured according to ASTM D1662. The specimen was cut into dimension of $30 \times 30 \times 30$ mm. The density of three specimens was measured and averaged. The density of foams is greatly affected by the blowing agent. Water is a low cost and readily available blowing agent used for preparing PUFs.²¹ Increasing the amount of water in the formulation of 1 to 10 parts per hundred parts of polyol (pphp), the density of foam decreased from 241 to 150 kg/m^3 (Figure 7). The observed decrease in density of the foam with increasing the amount of blowing agent is directly related to the cell size of the prepared foams. As the water content was increased the chemical reaction between water and TDI generates more amount of carbon dioxide, which is followed by more bubble formation. These bubbles coagulate resulting in bigger cell size due to which mass per unit volume decreases.

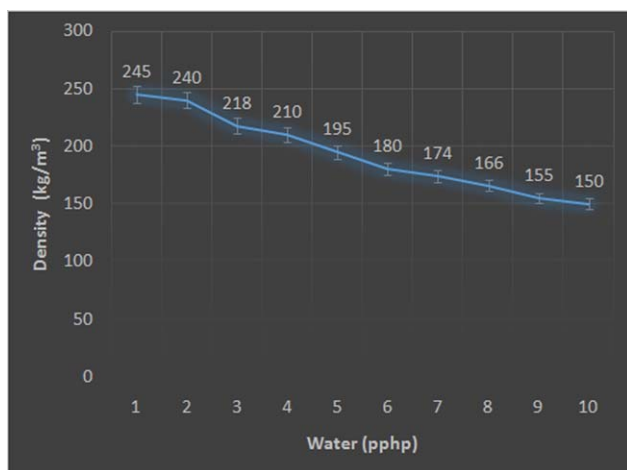


Figure 7. Density of the foams (pphp parts per hundred parts of polyol). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Compressive Strength. The compressive strength of the prepared PUFs samples was measured according to ASTM D 1521 under ambient conditions with Universal Testing Machine and strength decreased from 2.0 to 0.4 MPa as the water content in the formulation increased from 1 to 10 pphp (Figure 8). The obtained compressive strength of the prepared PUFs samples was comparatively good as compared to previous work done by Zhang *et al.* in 2014.³⁵

The reason behind the decrease in compressive strength again rests with the cell size of the obtained foam. The cell size of the foam increases with the amount of water which reduces the area of surface boundary around the bubbles and ultimately reduces the compression bearing capacity of the foam.

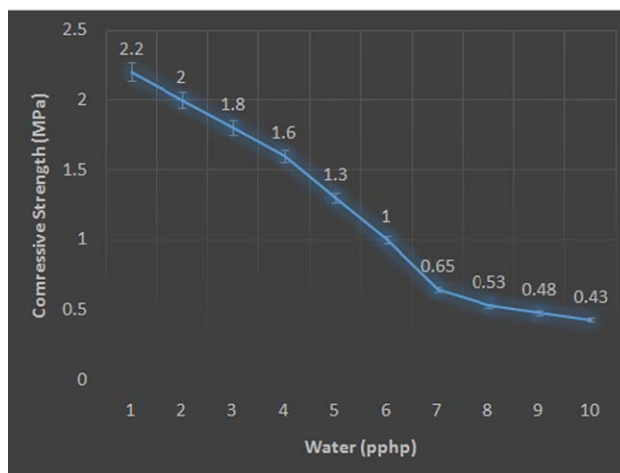


Figure 8. Compressive strength of the foams (pphp parts per hundred parts of polyol). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

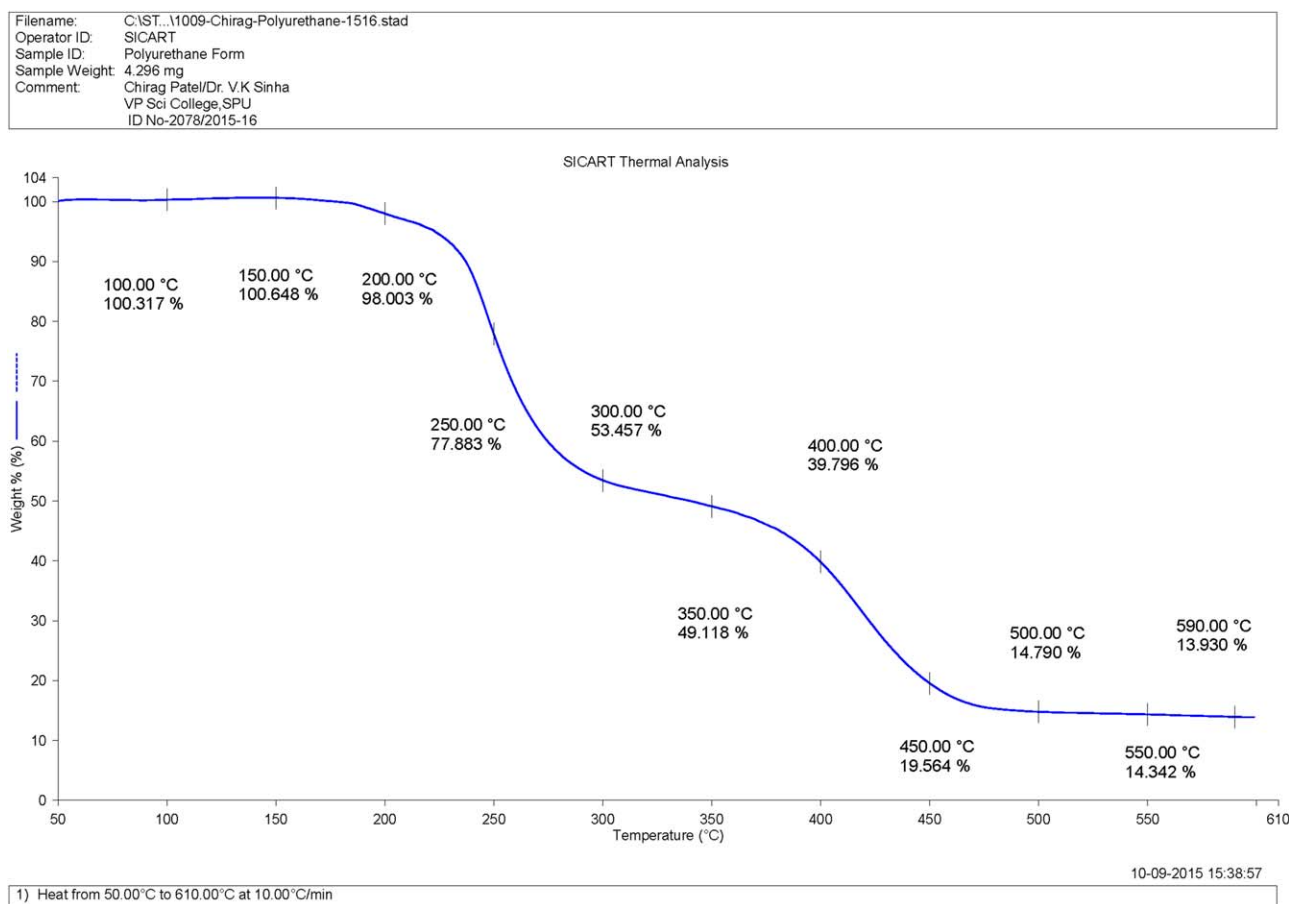


Figure 9. TGA graph of the polyurethane form (PUFs). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Thermal Conductivity Study. Thermal conductivity of polyurethane foam prepared from blend of castor and *N. tabacum* oil-based polyol was in the range of 0.013 to 0.017 Kcal/mh °C.

Thermal Analysis. TGA of one of the prepared foam sample (water 3 pph) having good mechanical property was done to evaluate its high temperature characteristics. TGA (Figure 9) showed dynamic weight loss during the heating periods. The degradation process was complex and depends on several factors

such as polyurethane linkages, unreacted isocyanate, and other products formed due to the reaction of isocyanate with other substances of the formulation. The obtained curve shows that the decomposition of foam started at around 180 °C due to the moisture. In the first stage, greater loss was observed between 200 °C and 250 °C. It can be seen that the fastest loss was between 300 °C and 400 °C, and the average loss for each 50 °C rise from 200 °C to 450 °C was 15.68%.

Morphological Characteristics. The cross-sectional SEM of the foam (Figure 10) consists of cells of nearly spherical, thin-walled and well-oriented shape. Cells of approximately 0.4 mm diameter and uniformly distributed were obtained. During the study, the sample having compact structure and more uniform and spherical-shaped pores resulted in higher compressive strength, which shows the importance of morphology of the foam on its mechanical strength.

CONCLUSIONS

The conceptual thought that the petrochemical source has to be supplemented by alternative source has been achieved by the use of biological source as polyol, that is, *N. tabacum* stalk, which is an otherwise waste material and finds use only in incineration.

The glycolglycoside synthesized was fruitfully converted into the polyol of required hydroxyl value, and it was further tailored to

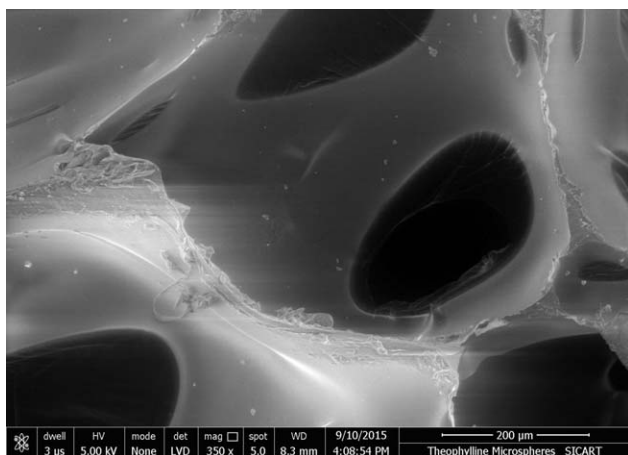


Figure 10. SEM of the prepared foam.

the required —OH value and mechanical and chemical property by addition of natural oil or synthetic diols. The synthesized polyols were further formulated leading to PU foams having characteristics and physical properties similar to the marketed foams. The physical properties like density and compressive strength were greatly influenced by the blowing agent and the amount of blowing agent, and these properties were found to have an inverse proportional relationship. Furthermore, the properties such as the thermal conductivity, thermal stability, as well as the morphological state leading to mechanical as well as thermal applicability were found to be in accordance to the requisite values. Thus, the optimized methodology has proven its track in obtaining the polymeric precursors from biowaste for a widely applicable polymeric system like foam.

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