ICACSIS 2014

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Advanced Computer Science and Information System 2012
(ICACSIS 2014)
Hotel Ambhara, Jakarta
October 18th - 19th, 2014

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A System Analysis and Design for Sorghum Based Nano–Composite Film Production

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***Abstract*— The existence of process complexity and higher inter–dependency within production system of biodegradable sorghum–based nanocomposite film are obviously required for system analysis and design. In this paper, nanocomposite film production was simulated in Business Process Modeling Notation (BPMN) model to assist researchers in decision making. The system was designed by using 2 processing variables as the model input, namely hydrolysis time and plasticizer ratio. Then by modifying and controlling value of these variables, researcher would determine their influences on 3 nanocomposite film crucial physical and thermal properties, such as Water Vapor Permeability (WVP), X–Ray Diffraction (XRD) and Derivative Thermo-gravimetric (DTG). Numerical examples were implemented in order to illustrate the related issues. Model verification result showed that the model succeeded conducting an improvement for all film properties compared to other various composites. Therefore this system is potentially possible to simulate sorghum–based nanocomposite film production in a simpler and fully controllable model.**

Keywords— System analysis and design, Business Process Modeling and Notation (BPMN), sorghum biomass, nanocomposite film, biodegradable

I. Introduction

Petroleum material that is generally used in packaging industry [1] nowadays have been turning into serious constraints by its non-biodegradable property which is hazardous to surrounding environment [2]. Besides, plastic recycle problem and fossil materials extinction motivate researchers to develop some other sustainable, environmental friendly, new materials to substitute synthetics polymer and mineral fillers. In recent years, natural polymers such as cellulose have been attracting not only researchers but also industry stakeholders as potential filler alternative [2,3,4], because since it is biodegradable and renewable [5] cellulose has high tensile strength and rigidity [6,7], high reinforcing potency and wide surface area [8]. Therefore, cellulose as natural resources is highly reasonable to replace petroleum or other synthetic polymer.

Cellulose is biopolymer that can be obtained from wood or non-wood resources. Non-wood substance likes agricultural residues is more preferable related to limitation in wood usages in last decade [9,10]. Sorghum biomass, which is generally used as feed, is able to be developed while in order to enhancing its added value it can be converted into high performance substitute matter [11]. Cellulose fiber as filler and reinforcing agent has many advantages such as specific surface area which can reaches hundreds m^2/g, very high elasticity modulus (Young), high ratio aspect, significant reinforcing ability even in smaller filler content, low density, non-abrasive, non-toxic, high visible light transmission, can be easily modified chemically because its structure has of –OH side group reactive surface, biocompatible, biodegradable, renewable, high availability so it is cheap, and environmental-friendly [12]. Those are technical reasons that insist cellulose based nanocomposite promising potency of being substitution material in term of packaging application development. Meanwhile, those complexity is considered as barrier for researcher before conducting the process in laboratory. Modeling comes as solution for this problem because we can simulate the process and controlling the variables as well to find whether there will be any improvement or optimization to the product.

In order to conduct improvement and/or optimization of the process, a modeling is applied in a system simulation. Many modeling method and computing languages have been studied to embrace all perspectives which are necessary in model such as information, functions and behaviors as much as possible. Business Process Modeling Notation (BPMN) as example attracts business engineers because it can define proses workflow in simpler and more flexible way and facilitate the execution which is simulated automatically linked to Business Process Modeling System (BPMS) [13]. Objective of this modeling using BPMN is to construct a simple and fully–controllable system presenting a real sorghum–based nanocomposite production process.

The reminder of the paper is organized as followed. In Section II, it provides clearer explanation about importance of determining variables used in this model, such as hydrolysis time and plasticizer ratio. It also tells the both general and specified objectives of modeling construction. In Section III, mathematical formulas applied in process are presented considering with model's objectives. Modeling methods conducted are also interpreted. This section defines how the system is developed sequ9entially and results and discussion after the production system model designed and analyzed and the verification of it afterwards. Lastly, its conclusion is written in Section IV.

II. Problem Statement

In cellulose nanostructure preparation, acid hydrolysis is one of most popular techniques which is able to break messy, separated and amorphous parts, and subsequently release it as well-blended single crystal component. Cellulose fiber was isolated from sorghum bagasse and was treated in sulfuric acid (H2SO4) in four varied hydrolysis times, 15, 30, 60 and 90 minutes, subsequently properties of Nano fiber produced were characterized. Afterwards, to construct Nano composite, Nano fiber was mixed into polyvinyl alcohol (PVA) with presentations of Nano fiber used were 0.5, 1 and 3 wt %. BPMN modeling of Nano composite properties characterization, consisting of XRD and WVP, aimed to evaluate the compatibility of Nano composite which its filler was made by sorghum bagasse cellulose Nano fiber related to influences of variables described before.

General objective of the modeling was to courage improvement of Nano composite properties by presented the processing condition system into a designed BPMN model. To succeed this purpose, there were specified objectives such as analyzing and identifying the influences of: 1) varied hydrolysis time; and 2) varied plasticizer ratio for nano-composite film production. Indicators targeted in this process were nano-fiber size of 1 to 3.5 nm and improved nano-composite‘s XRD and WVP, if compared to nano-composites made by other resources and methods. Responding to the objectives, capability expected to be existed in the built system was ability to design improvement model of nano-composite film production with two determining variables, which have been described above, and then analyze it, therefore optimum value could be identified in order to reach the best film characteristics.

III. Methodology

A. Mathematical Formulation

The system was formulated mathematically based on previous study. In former researches about nano-fiber based nano-composite, characterization of the sample is conducted to analyze whether the result shows an improvement compared to previous ones. Physical and thermal properties are ones of most important in film composite product assessment, such as Water Vapor Permeability (WVP), X-Ray Diffraction (XRD), and *Derivative Thermo-Gravimetric* (DTG).

A.1 *Water Vapor Permeability* (WVP)

WVP is water resistance properties of nanocomposite film which roles in maintaining the shelf-life of packaged product.

$$\mathrm{WVP} = \left(\frac{\mathrm{Flux}}{AP_0(\mathrm{RH}_1 - \mathrm{RH}_2)}\right) \times x \quad (1)$$

where x is film thickness (m), A is film surface area exposed to permeant (m^2), P_0 is vapor pressure of pure water (1753.55 Pa at 25 ^oC) and $(RH_1–RH_2)$ is relative humidity gradient used in experiment.

A.2 *X-Ray Diffraction* (XRD)

XRD is crystalinity index of nanocomposite film which roles in film structural stability. XRD is calculated in *x-ray* diffraction angle width of 5^o to 30^o (2θ) with power of 20 kV and 2mA.

$$\mathrm{CrI} = \left(\frac{I - I'}{I}\right) \times 100\% \quad (2)$$

where I is diffraction intensity assigned to (200) plane of cellulose and I' is intensity measured at 2θ – 18.

A.3 *Derivative Thermo-Gravimetric* (DTG)

DTG shows degradation temperature of nanocomposite film which roles in packaging quality and storage application. Thermal stability of few amount (mg) of sample placed on aluminum glass was tested in nitrogen condition and heating rate of 10 ^oC per minute.

B. *System Modeling*

Modeling stage role in identifying and decomposing business process so that system can be identified by detail and focused on control flow (sequence execution) or data flow (data exchange). In BPM, there are diagrams that relate each other in analyzing the model. Process Hierarchy Diagram (PHD) represents processes held in system into a hierarchy, where each process was analyzed one by one afterwards in Business Process Diagram (BPD). As addition, BPM also uses various languages representing its process, which one of them is analysis language that uses graphical notations standardized to illustrate control flow in Business Process Modeling Notation (BPMN). Required steps in analyzing and designing production system of nano-composite film made of sorghum biomass as its nano-filler are described below.

The following sub-sections describes more in detail about each steps and diagrams built in the modeling. First the system was defined and then its needs and variables were analyzed. After that, the diagrams' construction was started sequentially from Process Hierarchy Diagram (PHD), Business Process Diagram (BPD) until the last which was Business Process Modeling Notation (BPMN) [14].

B.1 *System Definition*

System is group of elements operated by integration, where each one has ability determined explicitly, that are able to work by synergic to process added values and offer users to satisfy their defined operational needs by result and success probability. System involves individual (organization), product and tools in several levels. In common, self-made system needs many levels of plans, operations, interventions and human resource support. System development is conducted if former system is no longer proper and compatible or able to meet the needs or updates occurred in the organization or firm. Development cycle or step in a system starts from planning, analysis, designing, implementation and maintenance, or well-known as System Development Life Cycle (SDLC) [15].

B.2 Requirement Analysis

System as a simple entity can be presented generally below. Necessary inputs are processed then generate outputs (products, by-products or services) aimed to solve problems and constraints. Meanwhile in analyst perspective, several critical information, which are describing how system operates, are gone. Those attributes are acceptable and unacceptable inputs, stakeholders, roles-missions-objectives, risks, controls, resources and acceptable and unacceptable outputs [15].

The important factor analysis was then solved by using *RELIEF* algorithm for its importance score by comparing them to the defined target. The higher score a factor of variable gets, the more important and crucial it is to the system. As ranking of variables' importance was achieved, some of top factor would be chosen as the determining factors discussed in model result.

B.3 Process Hierarchy Diagram (PHD)

The requirement for certain hierarchy structure implemented as a PHD. PHD is high level diagram that used to analyze business function as a hierarchy of process so it is also known as functional decomposition diagram. PHD illustrates graphically functions of the system and spreads them into many sub-processes.

B.4 Business Process Diagram (BPD)

In order to support business process clarity, BPD analyzes how many sub-processes of the system built by PHD being allocated to people, organizations or groups. This diagram determines the control flow of process and helps user to figure how data goes through them. BPD also defines the data flow influences on sub-processes implementation.

B.5 Business Process Model and Notation (BPMN)

PHD and BPD eventually lead to a BPMN. BPMN 2.0 version in this current work is standardized graphical notations so that is more easily to be understood not only by business stakeholders but also analyst and technical developers who have role in configuring and monitoring after the system implementation.

BPMN 2.0 consists of diagrams such as: 1) Conversation diagram overviews communication that linked between stakeholders. 2) Choreography diagram defines details of conversation held between two or more stakeholders that are drawn in specific conversation nodes. 3) Collaboration diagram describes messages flowing through the stakeholders. 4) Process diagram explains sequence flow of each process own by stakeholders.

In this modeling, choreography diagram is generally applied to illustrate the processing system by analyzing how each stakeholder switch and/or trade information and messages. The diagram coordinates the links by detail using the conversation nodes. Participants in the diagram represent firms, departments or divisions who have roles in system collaboration into swim lane, while they have not any separated unique symbols but names are written above or below choreography task symbol. Diagram's events are things happened in process and consisting of start, end, and intermediate activities, such as state and/or message changes, which are able to influence sequence and timing of model. Whereas another symbol in the diagram, gateways, controls the process' sequence flow like blend or separate away the flows behind gateway condition. Activities of diagram are works or tasks conducted in whole processes. Data is physical information made, manipulated or used in process execution while messages show contents traded between two or more stakeholders, and run through the flows.

Steps required to construct BPMN diagram are, in sequence, 1) determine departments involved in models and also each one's stakeholders and lists of their roles, 2) represent process flows conducted, 3) apply available notations then rearrange the orchestration, 4) complete the diagram with explanations and data, connect behaviors in the interactions between stakeholders then build choreography collaboration diagram and, last, recheck the model if it has any errors or warnings until the output intends there is zero mistakes.

Data implemented in order to execute the formulas was taken from literature, former researches which applied likely materials (soy, wheat, corn etc.) as Nano filler to manufacture the composite film. Cited articles, journals and reports chose the same variables to be observed each one's influences on process output. It was proved before that the impacts of chosen determining variables to the product were significant by statistics experimental design.

IV. EXPERIMENTAL RESULTS

Input of the system were derived from previous studies data [16.17,18,19] while some were hypothetical such as in variable analysis. Data were assumed by adjusting the range given in former researches' result with the system needs. Subsequently, output were confronted with reference data which had been best so far, so that existence of improvement could be analyzed.

A. System Development

Definition and development of the system will be described below. SDLC described that idea, as the first element which began the system [15], was production of sorghum bagasse cellulose Nano fiber based Nano composite film as a biodegradable and environmental friendly alternative in food packaging with improved properties. By analysis, required humans/users were researchers/lab workers, analysis, stakeholders in corporations related to composite, sorghum waste handling, food packaging and nanotechnology products. Production system requirement was determined by considering complexity in hydrolysis time and mixture solvent of cellulose Nano fiber cellulose–PVA Nano composite, risk plan in them and stakeholders communication. Afterwards, model could be designed by using success indicators. Model built then evaluated and tested before it could be deployed in Nano composite researches development and it has to be noted that maintenance is necessary before it comes back again to the starting point of idea generation.

TABLE I
VARIABLE ANALYSIS OF NANO-COMPOSITE PRODUCTION SYSTEM

T (°C)	WVP	XRD	DTG	Target
90	5.5	100	0	Δ
100	4	100	0.1	Δ
110	3.8	99	0.3	O
120	2.5	98	0.3	×
130	1.7	95	0.35	□
140	0.7	95	0.4	□
150	0.4	94	0.5	□

$$\begin{aligned}
WVP &= [\ (-1.5+1.8+3+3.8+4.8+5.1) + (0.2+1.5+2.3+3.3+3.6) + (1.3+2.1+3.1+3.4) + (0.8+1.8+2.1) + (-1-1.3) + (-0.3)\ ] / [\ 7 \times (100-94)\ ] \\
&= 41.9 / 35.7 \\
&= 1.174 \\
XRD &= [\ (0+1+2+5+5+6) + (1+2+5+5+6) + (1+4+4+5) + (3+3+4) + (0-1) + (-1)\ ] / [\ 7 \times (100-94)\ ] \\
&= 60 / 42 \\
&= 1.429 \\
DTG &= [\ (-0.1+0.3+0.3+0.35+0.4+0.5) + (0.2+0.2+0.25+0.3+0.4) + (0+0.05+0.1+0.2) + (0.05+0.1+0.2) + (-0.05+0.15) + (-0.1)\ ] / [\ 7 \times (100-94)\ ] \\
&= 3.5 / 3.5 \\
&= 1
\end{aligned}$$

Based on analysis result in nano composite production system variables shown in Table I, ranks of variables' importance could be achieved. In sequence, from the most important to the less important shown by each score, there were WVP of 1.174, XRD of 1.429 and DTG of 1. The two most crucial variables were chosen as determining variable in this model.

B. Model Analysis Result

BPMN diagram designed in this production system consists of 3 divisions and each one is divided into 2 sub-divisions. First division is *Isolation of biomass cellulose* which branches into sub-division *Biomass preparation/pre-treatment* and *Disk-milling*. Second division is *Cellulose Nano fiber production* which branches into sub-division *Cellulose hydrolysis* and *Nano-cellulose suspense dispersion*. Last is *Nano composite film production* which branches into *Film Formulation* and *Film Casting*.

There were critical tasks in diagram swim lane which define how the determining variables influence the process output. In Figure I, there is a division namely *Hydrolyzing cellulose isolate* where the impact of variable no.1, hydrolysis time, works. It was started by preparing the cellulose isolate. A start as starting point of the flow decomposes the processes [14]. As shown in diagram, the start event used is message start of top-level. A message represents the content of a communication between two participants using a flow. First message flow showed input message of cellulose isolate that is came from former participant in *Disk-milling* sub-division and afterward sent to the task receiving cellulose isolate.

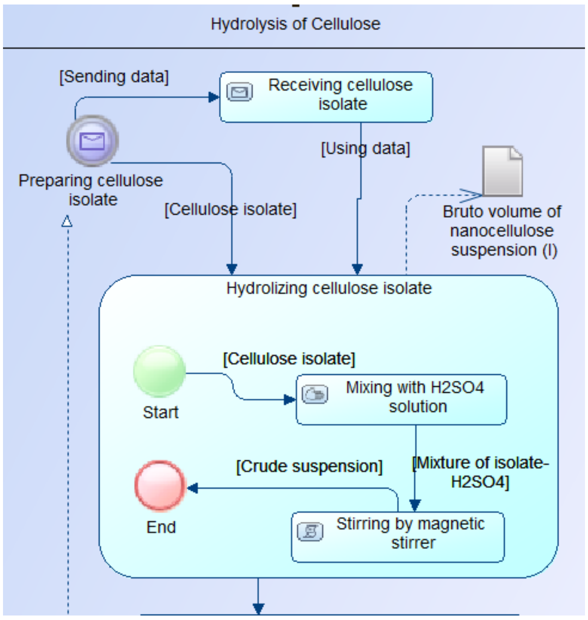

Figure 1. BPMN Swim-Lane of Cellulose Hydrolysis

Message flow in the diagram continued to deliver cellulose isolate from preparation in start event to sub-process of hydrolysis. Sub-process is an activity whose internal details have been modeled using activities, gateways, events and sequence flows [14]. Cellulose was mixed with sulfuric acid solution at first which defined as manual task. That manual icon means that the task is performed without aid of any business process execution engines or any other applications so it was held by human/operator self-hands. Next, there was script task, a task executed by script interpreted by a business process engine, namely stirring the mixture solvent using magnetic stirrer. It indicated that the task was conducted using engine power. It ended in end event by taking crude Nano cellulose suspension along in its message flow. Data association link showed the output information generated from this sub-process was gross volume of the suspense. The sequence flow steps forward to the next sub-process and divisions.

Another critical step in production system, film formulation, as same as it was in cellulose hydrolysis. It can be seen in Figure II the BPMN swim-lane of the process. *Film production* is the next division where variable no.2, plasticizer ratio, roles.

First, dispersed nano cellulose suspension was prepared by input message from former division. The suspense then continued to sub-process namely *Nano cellulose-PVA Nano composite formulation*. Suspense was mixed manually with PVA solution in various ratio of mixture. To make it well-dispersed, suspense was stirred using ultrasonic homogenizer. Mixture solution of film Nano composite formula then delivered to next division namely solvent casting to make the sheet of Nano composite film.

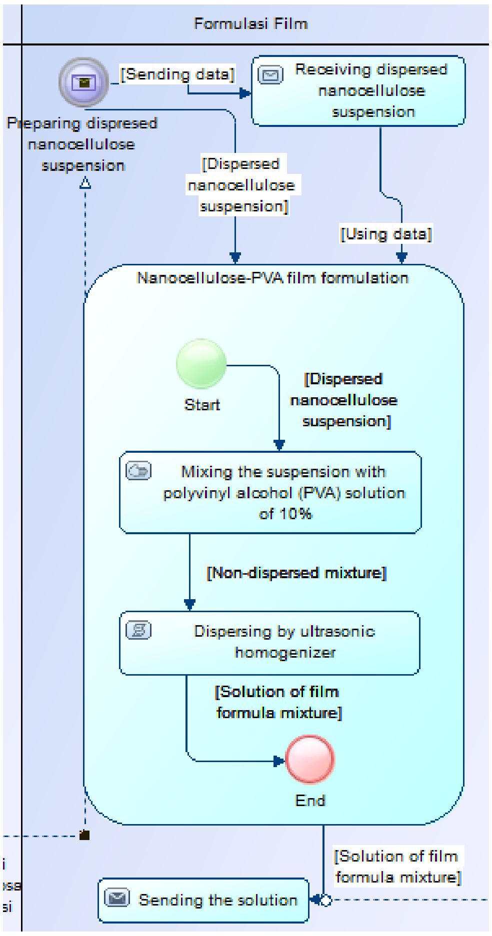

Figure 2. BPMN Swim-Lane of Film Formulation

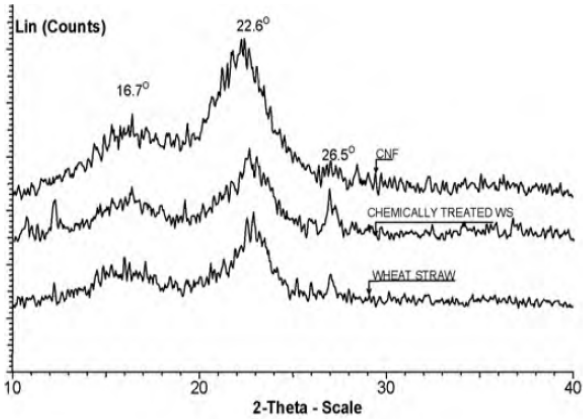

Figure 3. Comparison Graph of XRD

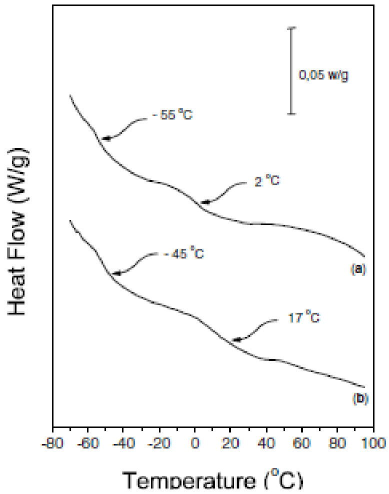

Figure 4. Comparison Graph of DTG

C. Model Verification

Based on formula and reference data gathered from previous studies [16.17,18,19], the designed production system model was compared then its improvement was analyzed. Comparison result was presented in graphs and tables. Each picture below defined difference conducted between sample's specific characteristics and reference data.

Figure IV showed that top and middle line, as sample, compared to two lines below, as other commercial matrix, indicated higher crystalinity which is good to film stability. It verified that the model is able to deploy an improvement, in case of XRD value.

Figure V showed that *a* line, which is sample, compared to *b* line, as other commercial matrix, indicated greater point of degradation temperature which is good to packaging or storage application It verified that the model is able to deploy an improvement, in case of DTG value.

Figure VI showed that sample compared to other commercial matrix indicated lower permeability of water content which is good to maintain the shelf-life of packaged product. It verified that the model is able to deploy an improvement, in case of WVP value. Those outputs were verified as improvement model in case of the cellulose nano fiber and nano composite properties.

V. Conclusion

Complexity in sorghum cellulose nanofiber–polyvinyl alcohol (PVA) based nanocomposite production and massive inter-dependencies among each processing steps were required in system analysis and design. Model was designed requiring hydrolysis time and plasticizer ratio as the input. Model output was to find out if there would be any improvement on XRD, DTG and WVP properties, as ones of the most crucial nanocomposite characteristics in packaging application. PHD and BPD diagram were built before making BPMN as the system analysis and design main tool. In conclusion, model validation result showed nill error and warning. Afterwards, in BPMN verification, sample and other composite comparison determined that all three properties indicated improvement. XRD was defined as the most crucial among other properties, confirmed by its value (1.4) as the highest in *RELIEF* measurement. This model is expected to be applied by researchers to assist them developing various nano-composite products and also for other fields as well.

Sample	WVP ($g\,m^{-1}\,s^{-1}\,Pa^{-1} \times 10^{-11}$)[a]	References
Nanofiber sheet	2.46	This work
ACNC-10	5.2	This work
Corn starch plasticized with glycerol	8.68	Piermaria, Pinotti, Garcia, & Abraham, 2009
Gellan gum plasticized with glycerol	20.8	Piermaria et al., 2009
Methyl cellulose	9.2	Park and Chinnan, 1995
Cellulose acetate/triethyl citrate/clay hybrid composites	NR	Park, Misra, Drzal, & Mohanty, 2004
Agar-based nanocomposite (10% clay)	150	Rhim, 2011
Cellophane	8.4	Shellhammer & Krochta, 1997
Sodium casein plasticized with glycerol	15.1	Piermaria et al., 2009
LDPE	0.036	Jiménez, Fabra, Talens, & Chiralt, 2012
HDPE	0.02	Smith, 1986
MFC (made from sugar beet)	NR	Leitner, Hinterstoisser, Wastyn, Keckes, & Gindl, 2007
NFC	NR	Svagan, Azizi Samir, & Berglund, 2007
ACNC	NR	Yousefi et al., 2010

Figure 5. Comparison Table of WVP

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