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Analysis of Measurement Uncertainty in the Calibration of Digital Scales in the Downstream CPO (Crude Palm Oil) Production Unit

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ABSTRACT
Calibration of measuring instruments is an important aspect in ensuring the accu-racy and reliability of industrial production systems, including in the palm oil derivatives (CPO) processing sector. Digital scales play a crucial role in the weighing process of raw materials, semi-finished products, and final products. However, each calibration process is inseparable from measurement uncertainty that can affect the quality of production results. Where this study aims to analyze the level of measurement uncertainty in the calibration process of digital scales used in CPO derivative production units. The research method is carried out by collecting scale reading data with standard loading, calculating type A (statistical) and type B (non-statistical) uncertainties, as well as calculating com-bined uncertainty and expanded uncertainty in accordance with ISO GUM (Guide to the Expression of Uncertainty in Measurement). Thus, the results of the analysis show that the greatest uncertainty comes from the variation in readings (repeatability) and the tol-erance of the standard weights used. The combined uncertainty value obtained is within the range that meets the industrial calibration tolerance limit, but there are recommenda-tions for improving environmental control procedures during calibration to minimize fur-ther deviations.

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INTRODUCTION

In the palm oil (CPO) processing industry and its derivative products, the accuracy of weight measurement is one of the most important factors to ensure the quality, quantity, and economic value of the product. Digital scales are used at various stages of production, from weighing raw materials, mixing additional materials, to packaging the final product. The slightest error in the weighing process can lead to product non-conformity, consumer claims, financial losses, and even violations of industry quality standards. Periodic calibration of digital scales aims to ensure that the measuring instrument works within the permitted tolerance limits. However, in every calibration process, there are elements measurement uncertainty which cannot be avoided. This uncertainty can come from many factors, such as instability of the scale reading, uncertainty of the weight standard, environmental variability (temperature, humidity), and limitations of the calibration method itself. Measurement uncertainty analysis is important to understand how reliable the calibration results are, as

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well as to meet the demands of international standards such as ISO/IEC 17025 which requires testing and calibration laboratories to report uncertainty values in each calibration certificate. In addition, the ISO GUM (Guide to the Expression of Uncertainty in Measurement) standard provides methodological guidance for calculating and expressing measurement uncertainty systematically. In CPO derivative production units, where the products are of high value and the production volume is large, failure to maintain the accuracy of weight measurement can have a direct impact on the company's reputation, compliance audits, and the efficiency of the production process. Therefore, this study aims to analyze the level of measurement uncertainty in the digital scale calibration process used in the unit, so that it can be used as a basis for improving the calibration system and better production quality control.

Literature Review

Control System

A control system can be said to be a relationship between components that form a system configuration that will produce the expected system response. So something must be controlled, which is a physical system, which is usually called a control (plant). Input and output are variables or physical quantities. Output is what is produced; while input is what influences control, which regulates output. The two dimensions of input and output do not have to be the same.

In the control system, there are open loop systems and closed loop systems. Open loop control systems or feed forward control generally use controllers and control actuators which are useful for obtaining good system responses. The output of this control system is not recalculated by the controller. A condition of whether the plant has actually reached the target as desired by the input or reference cannot affect the performance of the controller (Haris Abdul, 2014).

In other words, an automatic control system is a system that is able to regulate and control processes or equipment without direct human involvement. This system consists of sensor elements (for input), controllers, and actuators (for output). In modern industry, automatic control systems are used to improve efficiency, precision, and operational safety. In an automatic conveyor, the control system is responsible for regulating speed, stop position, and the order of transporting goods.

Calibration of Measuring Instruments

Calibration is the process of comparing the measurement results of a measuring instrument against a reference standard whose value is known, to determine the accuracy and traceability of the instrument. According to ISO/IEC 17025, calibration aims to:

Determining the deviation or correction of measurement results, Ensure measuring instruments meet technical specifications, and Ensuring the conformity of measuring instruments to national and international standards. In the context of digital scales, calibration is carried out using certified standard weights. A Digital Scales is a mass measuring instrument that converts the gravitational force on an object into an electrical signal via a load cell and processes it into a digital reading. The main components of a digital scale include:

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Load cell: A sensor component that detects changes in pressure into an electrical signal. Amplifiers and A/D converters: Convert analog signals into digital data. And Microcontroller: Manages the reading data and displays it on the screen.

The performance of digital scales is affected by factors such as temperature, humidity, load cell wear, and electrical interference. Measurement uncertainty is a non-negative parameter that characterizes the distribution of measurement results based on available information. According to ISO GUM (Guide to the Expression of Uncertainty in Measurement), uncertainty reflects the level of confidence in the measurement results. Types of uncertainty:

1. Type A uncertainty: Obtained from statistical evaluation based on a series of repeated measurements (repeatability).
2. Type B Uncertainties: Obtained from information other than experimental data, for example from calibration certificates, manufacturer's specifications, or assumptions.

The combined uncertainty is calculated by combining all sources of uncertainty using the root sum square method, and the expanded uncertainty is obtained by multiplying the combined uncertainty by an expansion factor (k), usually k=2k=2 for a 95% confidence level. General steps in the digital scale calibration procedure:

1. Preparation of equipment and environment (conditioning temperature, humidity, and stability of the scale surface).
2. Carry out loading with standard weights.
3. Read the value shown by the scale.
4. Calculating the deviation (difference) between measurement results and standard values.
5. Determine correction values and calculate measurement uncertainty.
6. Create a calibration certificate that includes the correction values and their uncertainties.

Understanding Control System Accuracy

Accuracy in control systems refers to the ability of a system to execute commands or maintain output at a desired value (setpoint). In the context of an automated conveyor system, accuracy includes the ability of the system to stop an object at the correct position, at the correct time, and consistently. Accuracy measures how close the system's output is to the target value or setpoint. For example, if the conveyor is supposed to stop an object at a position 100 cm from the starting point, and the system stops at 101.2 cm, then there is an accuracy deviation of +1.2 cm. Simple accuracy formula:

Accuracy = |Actual value – Setpoint value|

In PLC control systems, accuracy is greatly influenced by:

a. Sensor resolution
b. Actuator response time
c. Conveyor motor speed stability
d. Latency in PLC logic processing

Precisionmeasuring the consistency of system results against repeated experiments, although the results are not always accurate. A system is said to be precise if it is able to

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provide the same results repeatedly, although the value is not necessarily close to the setpoint.
Example: If the conveyor repeatedly stops at the 101.2 cm point (with a constant deviation), then the system is precise but not necessarily accurate.
High precision → consistent
High accuracy → close to target
Ideal → accurate and precise at the same time.

Crude Palm Oil (CPO)

Crude palm oilor palm oil is the main raw material used to make cooking oil. Crude palm oil is unrefined crude palm oil. Crude palm oil is obtained from the extraction or pressing process of oil palm fruit flesh. This CPO is obtained from various CPO producing regions such as Sumatra and Kalimantan. The CPO received by PT. Salim Ivomas Pratama is already in liquid or paste form. CPO is a slightly thick, reddish-orange vegetable oil that contains free fatty acids and lots of provitamin A. Crude palm oil is different from palm kernel oil, even though both are produced by the same fruit. In addition, crude palm oil is also different from coconut oil produced from the kernel of the coconut fruit (Cocos nucifera). This difference lies in the content of each type of oil. CPO basically has a reddish color due to the high beta-carotene content. Beta carotene itself is a precursor compound to vitamin A which is also a dominant red-orange pigment that is naturally present in plants including fruits. Meanwhile, palm kernel oil does not contain beta-carotene so that the color composition is different. The difference in saturated fat content between crude palm oil, coconut kernel oil, and coconut oil is quite significant, namely 41%, 81%, and 86% respectively. There are several general CPO content limits as follows:

Table 1. General Parameters of Crude Palm Oil (CPO)

Parameter	Condition
Free Fatty Acids	Max 0.5%
Water	Max 0.5%
Impurities	Max 0.5%
Iodine Number	50-55 gr iodine/100 gr CPO
Color	Reddish orange

Phosphoric Acid (PA)

Phosphoric acid or commonly known as orthophosphoric acid or phosphoric acid with the chemical formula H3PO4, molecular weight 98 g/mol boiling point 135°C is a liquid and colorless chemical compound. Phosphoric acid is a supporting material in the CPO refining process. Phosphoric acid has properties such as odorless and non-volatile. The main component of phosphoric acid is phosphorus obtained from phosphate rock. In its application, phosphoric acid is widely used as a raw material for fertilizer. In addition, phosphoric acid can be used as an ingredient in detergents, floor cleaners, pesticides, food ingredients (lysine and MSG production), textiles, etc. Phosphoric acid is also used as a supporting material in the refinery process. In the refinery process, phosphoric acid is used as a remover of sap or gums in CPO during the degumming stage. Phosphoric Acid used in CPO processing usually has a concentration of 85%. Before phosphoric acid is used in the

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production process, phosphoric acid obtained from the producer will be checked first in Quality Control (QC) to determine whether the content in phosphoric acid is in accordance with the levels determined by RnD.

Bleaching Earth (BE)

`Bleaching Earthis the result of clay minerals, bentonite and montmorillonite which are processed for the needs of refining vegetable oil and animal fat so that it can be consumed by humans. Bleaching Earth is a supporting material in the CPO refining process. The use of bleaching earth can break down dirt and unwanted materials usually in palm oil, such as dyes (carotenoids), soap and others, which can be found in oil and fat. In the manufacture of palm oil, oil color is an important part. The color of the oil will greatly affect the quality of the oil produced. To meet consumer desires, bleaching that meets standards is needed. The use of bleaching materials or Bleaching Earth (BE) which is often referred to as an adsorbent is the main choice for carrying out this process. The types of Bleaching Earth are bentonite, activated charcoal, and simnite. The name Bleaching Earth comes from its ability to remove color pigments from oil and other chemicals. The addition of BE depends on two factors, namely the quality of the CPO and the quality of the oil to be produced. BE before being used in the production process will be checked first in the QC laboratory with test parameters of bulk density, moisture, acidity, pH, and blanching power. Blanching power is the most critical parameter in BE, because BE is an important component for blanching the color of oil.

Poly Ethylene Therephthalate (PET).

Polyethylene terephthalate(PET) is a versatile thermoplastic polymer belonging to the polyester polymer group. Polyester resin itself is known for its superior properties in terms of mechanical, thermal, and also chemical resistance. PET has harder and stiffer characteristics than PBT, besides it is also very hard and light so it is easy and efficient to be used as packaging. PET is very suitable for use as a bottle because the color of the resulting bottle will be clear or not opaque. But PET also has weaknesses such as not being impact resistant when compared to PBT and also more difficult to shape when compared to PBT. At PT. SIMP uses PET as the basic material for making bimoli bottles as the basis for making classic bimoli bottles in sizes 250 mL, 620 mL, 1000 mL, and 2000 mL.

High Density Poly Ethylene (HDPE)

HDPE has a fairly long single polymer chain that makes this type of polymer quite dense, strong, and thicker when compared to PET. HDPE is usually used as shopping bags, milk cartons, juice bottles, shampoo bottles and medicine packaging bottles. HDPE (high density polyethylene) has stronger, harder, opaque and more resistant to high temperatures. HDPE at PT. SIMP is used as a material for making classic bimoli bottle caps. This material is strong but flexible enough to be used as a bottle cap material.

Low Linear Density Poly Ethylene (LLDPE)

LLDPE Plasticis a type of polyethylene plastic, a type of thermal plastic that is produced and formed by heating. LLDPE is a mixture of LDPE so that it has a stronger tensile strength and at the same time is also soft so that it can be more flexible. Unlike HDPE and LDPE, its molecular branches also tend to be short so that the reaction between

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molecules is not so strong. The intermolecular looseness makes LLDPE tend to be soft and flexible. Its tensile strength tends to be high so that it can widen to stretch compared to similar materials such as HDPE and LDPE. This type of plastic has quite good resistance to chemicals and pressure, but cannot accommodate gas-type materials. With a density of around 0.93 g/cm^{2}good for holding back water vaporization. PT. SIMP obtains LLDPE from suppliers which is used as a material for making bimoli bottle caps in sizes 250 mL, 620 mL, 1000 mL, 2000 mL.

METHODS

This study uses a descriptive quantitative approach, namely by collecting digital scale calibration data and analyzing measurement uncertainty based on scientific method standards, especially according to the ISO GUM (Guide to the Expression of Uncertainty in Measurement) guidelines. This study uses a descriptive quantitative approach, namely by collecting digital scale calibration data and analyzing measurement uncertainty based on scientific method standards, especially referring to the ISO GUM (Guide to the Expression of Uncertainty in Measurement) guidelines. The results of the data analysis show that the combined uncertainty values are within the acceptable tolerance range for industrial use. The largest contribution to the uncertainty comes from the repeatability of the load cell (repeatability of sensor readings) and the tolerance of the standard weights. Environmental fluctuations, although small, also contribute to the total uncertainty. Improved environmental control during the calibration process, such as room temperature stabilization, can further reduce the total uncertainty level. Reliable measurement data supports production consistency and compliance with regulatory standards. The calibration process of digital scales is inherently affected by measurement uncertainty. Through systematic analysis, this study shows that proper calibration and accurate uncertainty estimation can ensure the reliability of the weighing system in CPO derivative production. The implementation of robust calibration practices and effective management of environmental factors are essential to maintain weighing accuracy and improve production quality.

RESULT

Production Process

Crude Palm Oil (CPO) serves as the primary raw material for producing oil-based products at industry. The first stage of processing takes place at the refinery, which consists of four main sections: degumming, bleaching, filtration, and deodorization. During degumming, CPO is subjected to high-temperature heating and mixed with phosphoric acid (PA) while being continuously stirred to ensure even distribution. The purpose of this step is to eliminate phosphate-based gums that could otherwise interfere with the subsequent bleaching process. Following this, the mixture moves to a slurry tank, where bleaching earth (BE)—delivered from a dedicated silo—is added. BE helps decolorize the oil and absorb residual impurities from the degumming stage. A higher quantity of BE typically indicates lower quality of the incoming CPO. The slurry then flows to the sparging unit, where it is

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stirred under controlled pressure. This combined degumming and bleaching process results in Degummed Bleached Palm Oil (DBPO).

The next stage is filtration, which involves three Niagara filters operating in batches. All three filters work together to ensure uninterrupted production; however, if one filter is down for maintenance or repair, the capacity is affected. This stage removes bleaching earth and any residual impurities, clarifying the CPO. Waste oil mixed with dirt (known as *blotong*) is either sent to a slop tank or recirculated to the bleaching section. The filtered oil is then temporarily stored in a filtrate tank, followed by further filtration via a bag filter. Before entering the deodorizer, DBPO is reheated to prepare for the next stage.

The deodorization process uses high temperatures to reduce both the oil's color and its Free Fatty Acid (FFA) content. It also removes unwanted odors by exploiting the different boiling points of the oil components. This results in two key products: Refined Bleached Deodorized Palm Oil (RBDPO) and Palm Fatty Acid Distillate (PFAD). RBDPO proceeds to the fractionation plant, while PFAD, a by-product, is collected and can be repurposed for soap and cosmetic manufacturing.

Inthe Fractionation Plant, RBDPO is separated into two components: stearin and olein. Stearin is used in producing margarine and shortening, whereas olein is processed and packaged as cooking oil. This plant has two stages: crystallization and filtration. In crystallization, RBDPO is cooled until it forms a solid phase (stearin) and a liquid phase (olein). The mixture is then filtered, separating stearin (retained in a filter press) from olein, which is collected in a storage tank before moving on to the packaging facility. For bottle production, PET (Polyethylene Terephthalate) pellets are used in a molding machine. Caps are made using HDPE (High-Density Polyethylene) mixed with pigments, while handles are made similarly using polypropylene as the base material. All raw materials, products, and additives (like phosphoric acid and bleaching earth) undergo analysis by the Quality Control department before use, ensuring compliance with quality standards.

Refinery Process

The overall CPO processing involves two primary stages: refining and fractionation. Initially, CPO is received from belawan and stored in receiving station tanks, where it is continuously heated to prevent solidification and to facilitate the removal of impurities like dirt and moisture. The heating is done with steam at 45–55°C. From the tanks, CPO is transferred to the refinery plant, where the goal is to reduce or eliminate unwanted substances such as fiber, moisture, insoluble components, FFA, phospholipids, heavy metals, oxidation products, and odor-causing compounds. There are three refinery units at the Surabaya facility, each using different processing licenses:

a. Refinery 1 – LURGI
b. Refinery 2 – ALFA LAVAL
c. Refinery 3 – LIPICO

Each unit operates through the same core stages: degumming, bleaching, filtration, and deodorization. In degumming, phosphoric acid (H_3PO_4) is used to remove gums. The bleaching section uses Bleaching Earth to reduce oil color and absorb leftover

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contaminants. After filtration, DBPO is obtained. In the final deodorizing stage, the oil undergoes high-temperature treatment to eliminate odor and lower FFA levels, producing RBDPO.

Throughout the entire refinery process, operations are performed under a vacuum system to prevent hydrolysis and oxidation, which could damage the oil. Hydrolysis occurs in the presence of water vapor, while oxidation results from oxygen exposure—both are detrimental to oil quality.

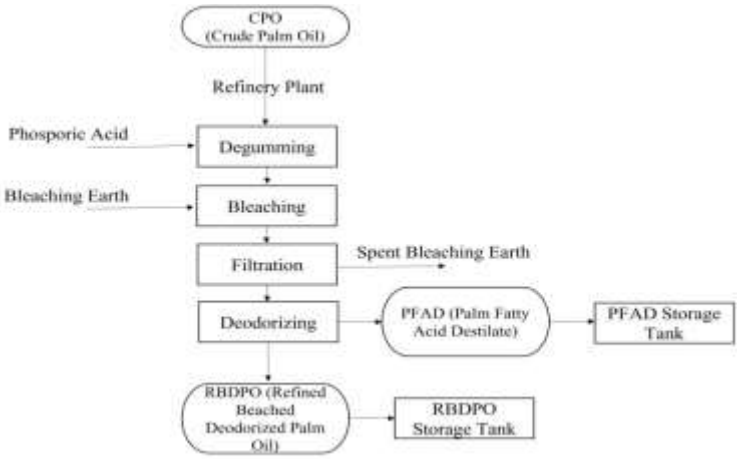

Figure 1. Flowchart System

Preparation of Catalyst for Ash of CPO

CPO taken from the empty oil palm bunches burning furnace of Ganda Makmur PKS was filtered with a 120 mesh sieve. Furthermore, the ash was calcined at a temperature of 700°C for 5 hours to remove carbon residues. Furthermore, potassium content test was carried out in ATKKS using an atomic absorption spectrophotometer. FFA value measurement (ASTM D 664) 2-3 grams of CPO added 15 mL of hexane then added 20 mL of 95% alcohol and added 3-4 drops of phenolphthalein indicator then titrated with 0.1 N KOH. The addition of KOH causes the phenolphthalein indicator to react by changing color to pink. Then the KOH data is used to perform calculations.

$$\%FFA = \frac{\text{ml KOH} \times \text{M KOH} \times \text{BM Oil}}{\text{Sample weight} \times 1000} \times 100\%$$

CPO as much as 150 mL was heated using a hot plate until the temperature reached ± 60°C. The oil was added with 60 mL of methanol and 2 mL of 98% H2SO4 then heated for 2 hours while stirring using a magnetic stirrer. The esterification results were centrifuged for 3 minutes at a speed of 1600 rpm. Furthermore, the esterification results were separated by taking the top layer which will be used in the next process, namely the transesterification reaction (Sundaryono, 2011).

Transesterification Process 100 mL of esterified CPO was put into a beaker 250 mL and heated until it reaches a temperature of 60°C. After the temperature is reached, the catalyst of oil palm empty fruit bunches ash is added in 60 mL of methanol with variations of 1% (w/v), 2% (w/v) and 3% (w/v), then heated at a temperature of 55oC for 2 hours

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while stirring using a magnetic stirrer. After the heating and mixing process is complete, the mixture is centrifuged for ± 3 minutes. After sedimentation occurs, separation is carried out by taking the top layer in the form of liquid (biodiesel) (Sundaryono, 2011).

Quantitative analysis of biodiesel characteristics refers to SNI 04-7182-2006. The parameters tested include measurements of density, viscosity, water content, acid number, iodine number, saponification number, cloud point and cetane number. Specific gravity indicates the comparison of weight per unit volume. The specific gravity of biodiesel is measured using a pycnometer. First, a dry and clean empty pycnometer is weighed. Then the sample is inserted into the pycnometer without any air bubbles and the outside of the pycnometer must be clean and then weighed. Specific gravity calculated using the formula:

Density (p) $\frac{m_{piknometer} + sampel + m}{V_{pinometer}}$ The best way to get rid of the virus

CPO Catalyst Preparation

The CPO used in this study came from the burning of empty oil palm bunches at PKS Ganda Makmur, Wiwirano District, North Konawe Regency. The preparation process was carried out by filtering the ATKKS using a 120 mesh sieve. Furthermore, the ash was calcined at a temperature of 700°C for 5 hours in order to remove carbon residues. In this study, an analysis of empty oil palm bunch ash was carried out using an atomic absorption spectrophotometer (AAS) to determine the potassium content.

Figure 2. Oil palm empty bunches burning furnace

The standard curve of potassium obtained is shown in Figure 2. In this study, the calibration curve serves to prove the linearity between absorbance and concentration in the research concentration area. From the results of the calibration measurements, it is shown that between absorbance and concentration is very linear with R2 = 0.9085. The calibration curve is obtained by plotting concentration against absorbance to obtain a straight line equation: y = = 0.0538x + 0.0284.

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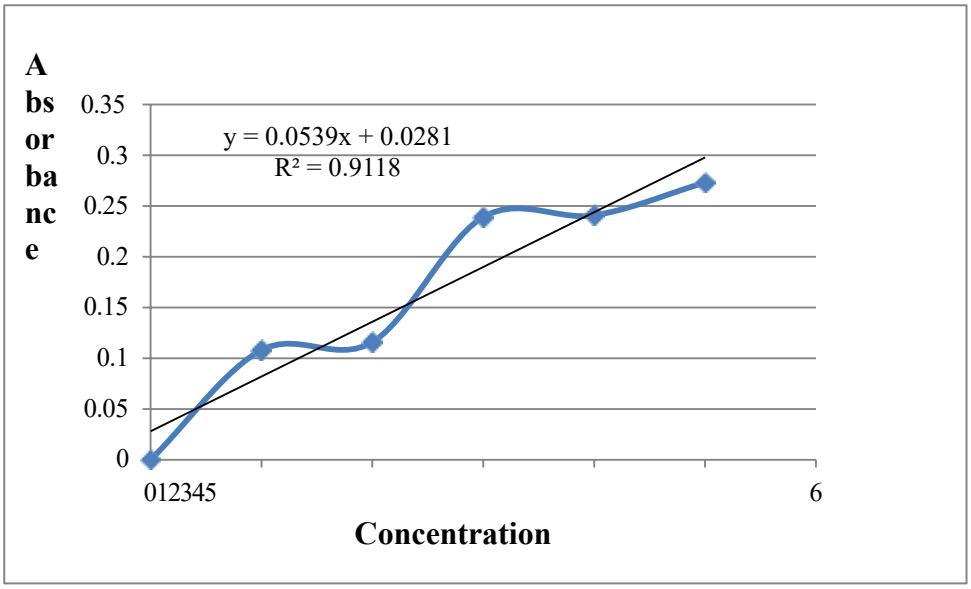

Figure 3. Calibration curve of ATKKS potassium

The results of research on the use of ATKKS as a catalyst in the manufacture of biodiesel conducted by Pratama et al., (2009) stated that ATKKS is basic because the composition of ATKKS contains potassium carbonate (K2CO3). Based on the results of atomic absorption spectrophotometer analysis, the potassium content in ATKKS in this study was obtained at 27.14 g/Kg. The potassium content is not much different from the potassium content obtained by Pratama et al., (2009) of 25.92 g/kg. Based on the level of basicity as a source of alkoxide and its relative concentration in empty oil palm fruit bunch ash, the type of cation that plays an important role in the base catalysis reaction is potassium.

Determination of Free Fatty Acid Content of CPO

Free Fatty Acids (FFA) is a value that indicates the amount of free fatty acids in fat or the amount that indicates how much free fatty acids are in fat after the fat is hydrolyzed. Free fatty acids are fatty acids that are separated from triglycerides, diglycerides, monoglycerides, and free glycerin. This can be caused by heating and the presence of water in the sample so that the hydrolysis process occurs. Oxidation can also increase the levels of free fatty acids in vegetable oil (Hasahatan et al., 2012).

The process of determining FFA in raw materials is a determining factor in choosing the type of biodiesel production process. Based on the results of the analysis of the free fatty acid content of CPO as raw material in this study, it was 5.47%. The percentage of FFA obtained is not yet suitable as a raw material requirement for biodiesel production with a transesterification reaction. Ramadhas et al. (2005) stated that oil with a high fatty acid content (> 2% FFA) is not suitable for use as raw material in the transesterification reaction. A two-stage reaction is needed, namely esterification and transesterification, to reduce the fatty acid content to <2%. Therefore, determining the FFA content in raw materials is very important before being processed into biodiesel.

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The esterification reaction is a reaction between free fatty acids and alcohol to form esters, as a preliminary reaction of the transesterification reaction with the purpose of reducing free fatty acid levels. The esterification reaction is also an endothermic equilibrium reaction with an acid catalyst. Given the raw material of oil with a high fatty acid content of 5.47% if used as a raw material in a base-catalyzed transesterification reaction, the fatty acid will react with the catalyst to form soap through a saponification reaction, so that the effectiveness of the catalyst will decrease because some of the catalyst reacts with fatty acids. This method begins with the esterification stage which aims to reduce FFA from oil where the fatty acid will be converted into ester form.

Esterification is generally carried out by conventional heating using a proton donor acid catalyst such as sulfuric acid (H2SO4) and methanol as the type of reactant alcohol considering that methanol is a short carbon chain alcohol compound and is polar, so it can react faster with fatty acids and can dissolve all types of catalysts, both base and acid, and is more economical. The esterification reaction is carried out at a temperature of 60 ° C for 2 hours and continuous stirring is carried out to accelerate the reaction and so that all catalysts can react with the reactants. The results of the esterification reaction obtained 3 phases, namely triglycerides, glycerol and water as shown in Figure 8. Separation is carried out using a centrifuge to separate the upper and lower layers based on their specific gravity.

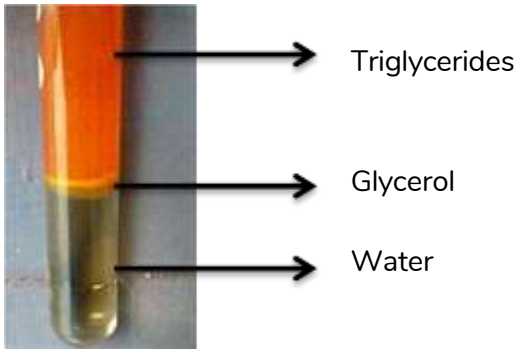

Figure 4. Esterification Results

The esterification results were then analyzed for free fatty acid content by titration using KOH and phenolphthalein indicator which was marked by a change in the color of the solution from yellow to pink. By achieving the titration equivalence point, the acid number of CPO can be determined. So based on the results of the esterification reaction with H2SO4 catalyst, the free fatty acid content was reduced to 0.57%. The mechanism of the esterification reaction with an acid catalyst can be seen in Figure 5.

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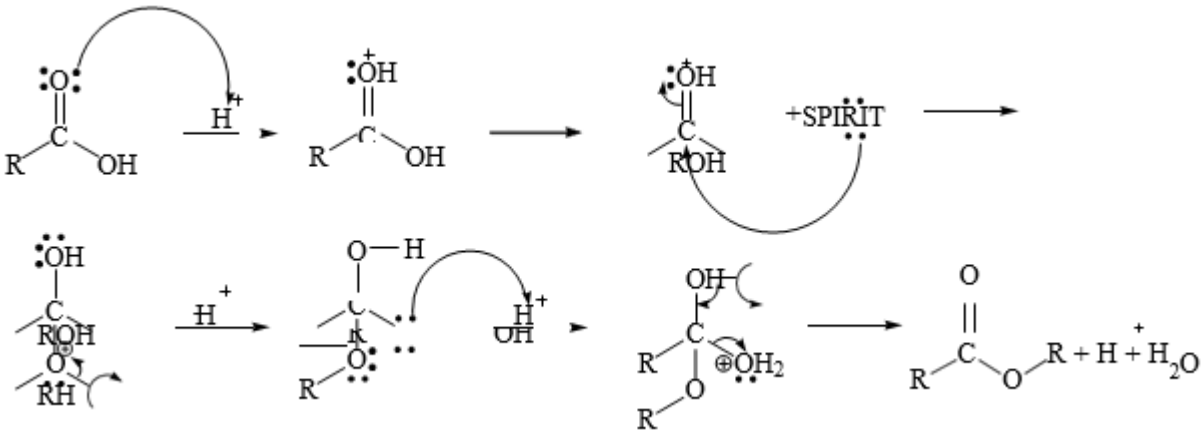

Figure 5. Mechanism of esterification reaction with acid catalyst (Muin, 2013)

In the transesterification stage using methanol as a solvent and K2O from CPO as a catalyst. In this study, a base catalyst (K2O) was used, because it reacts faster than an acid catalyst.

Table 2. Yield of CPO Methyl Ester

% Catalyst	Methyl ester weight (grams)	CPO weight (grams)	Yield (%)
1	20.25	89	22.75
2	24.3	89	27.30
3	28.35	89	39.33

Yield is the ratio of the weight of biodiesel to the weight of the initial oil. The main factors that affect the yield of esters produced in the transesterification reaction are the molar ratio between triglycerides and alcohols, the type of catalyst used, reaction temperature, reaction time, water content and free fatty acid content in the raw material that can inhibit the reaction. To evaluate the performance of the ATKKS catalyst, a performance test was carried out on the yield of biodiesel. Figure 12 shows a graph of the yield and characteristics of biodiesel produced using the ATKKS catalyst with a variation of % catalyst 1-3%(b/v).

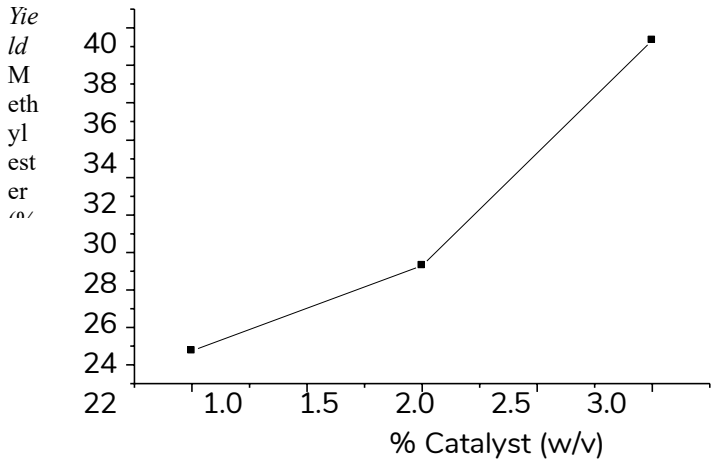

Figure 6. Graph of the relationship between methyl ester yield and % K2O catalyst.

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Overall, 3% (w/v) has a higher yield. good compared to the catalyst weight of 1 and 2% (w/v) on biodiesel yield. The results obtained are inversely proportional to the results of the study conducted by Ritonga MY et al., (2013) with the same percentage variation of catalyst where the greater the amount of catalyst, the lower the yield of methyl ester. Catalyst weight is one of the determining factors in the reaction rate. Yield is not the only data used as a reference to determine the quality of biodiesel. Yield does not indicate the conversion of palm oil to biodiesel, because there is a possibility that some palm oil that is not converted to biodiesel is still contained in the reaction product. Therefore, other data such as viscosity, specific gravity, acid number, saponification number, iodine number, cloud point, cetane number and water content are needed.

The resulting methyl esters were then analyzed using a GC-MS tool with the aim of determining the components and other components contained in the biodiesel and determining the quantity of each component by producing spectral peaks, each of which indicates a specific type of methyl ester as shown in Figure 7.

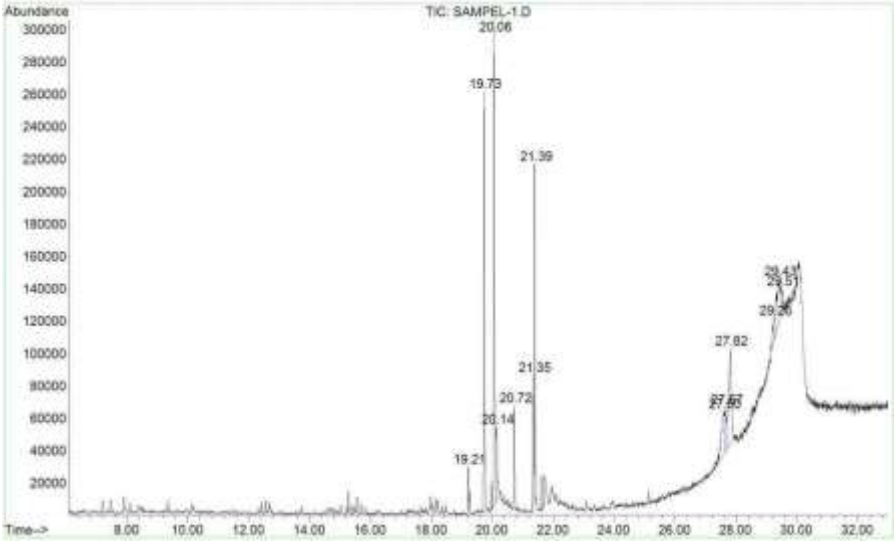

Figure 7. GC chromatogram of biodiesel sample

Furthermore, each peak in the GC chromatogram was further identified using a mass spectrometer, where each compound has a specific mass fragmentation pattern. The results of the GC-MS analysis showed that of the 12 compounds contained in the GC chromatogram, only 3 compounds were methyl ester compounds, namely methyl hexadecanoate (methyl palmitate), methyl 9,12-octadecadienoate, and methyl 9-octadecenoate. Other compounds are likely only alkyl ester derivatives of each fatty acid. The highest ester content in biodiesel is methyl hexadecanoate which is indicated by peak number 2 with a compound content of 17.75%. The methyl ester content in the resulting biodiesel is shown in Table 3.

Table 3. Types of Methyl Ester Compounds in Biodiesel

No	Retention Time (minutes)	Compound Name	% Compound	m/z
1	19.21	1,2-Benzenidacarboxylate	1.11	223
2	19.72	Methyl Hexadecanoate	17.75	270

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No	Retention Time (minutes)	Compound Name	% Compound	m/z
3	20.06	Hexadecanoic acid	22.66	263
4	20.14	Hexadecanoic acid	4.26	256
5	20.72	7-Pentadecine	3.78	260
6	21.34	Methyl 9,12-octadecadienoate	3.97	294
7	21.39	Methyl 9-octadecenoate	12.06	296
8	27.59	2-methyl-7-phenylindole	7.08	439
9	27.67	Acetamide	3.10	439
10	27.81	1-methyl-2-phenylindole	12.60	591
11	29.43	1,2,4-Benzenetricarboxylate	8.78	550
12	29.51	Hexamethylcyclotrisiloxane	0.92	550

CONCLUSION

Based on the analysis conducted, it can be concluded that the calibration process of digital scales in the downstream CPO production unit involves several significant sources of measurement uncertainty, including variations in scale readings, reference weight inaccuracy, and environmental factors such as temperature and humidity. The uncertainty was calculated using a combined approach of Type A and Type B uncertainties, and then expanded using a coverage factor to achieve a 95% confidence level. The results show that the measured uncertainty values remain within acceptable industrial calibration standards. Therefore, the digital scales in use are still suitable for operational purposes in the production process. However, regular monitoring and control of environmental conditions are necessary to ensure the traceability and reliability of measurement results. A systematic and well-documented calibration procedure is essential to maintain measurement accuracy and support product quality in downstream CPO processing.

REFERENCES

[1] Aryza S, Et Al (2024). A Robust Optimization To Dynamic Supplier Decisions And Supply Allocation Problems In The Multi-Retail Industry *Eastern-European Journal Of Enterprise Technologies*, (3).

[2] Adi Sastra T, etal (2022),). Perancangan Otoped Listrik Menggunakan Panel Surya Sebagai Media Transportasi. *RELE (Rekayasa Elektrikal dan Energi): Jurnal Teknik Elektro*, *5*(1), 62-65

[3] Anisah, S., Fitri, R., Taro, Z., & Wijaya, R. F. (2022). Comparison of Lighting Efficiency (Led-CFL) based on Environmentally Friendly Technology. *Journal of Applied Engineering and Technological Science (JAETS)*, *4*(1), 568-577.

[4] Bolton, W. (2015). Programmable Logic Controllers (6th ed.). Elsevier.

[5] BIPM, IEC, IFCC, ILAC, ISO, IUPAC, IUPAP, & OIML. (2008). Evaluation of measurement data — Guide to the expression of uncertainty in measurement (JCGM 100:2008).

[6] Christopher, M. (2016). Logistics and Supply Chain Management (5th ed.). Pearson UK.

[7] Nise, N.S. (2011). Control Systems Engineering (6th ed.). John Wiley & Sons.
[8] Ogata, K. (2010). Modern Control Engineering (5th ed.). Prentice Hall.
[9] International Organization for Standardization. (2008). ISO/IEC Guide 98-3:2008 - Uncertainty of measurement - Part 3: Guide to the expression of uncertainty in measurement (GUM:1995). ISO.
[10] International Organization for Standardization. (2017). ISO/IEC 17025:2017 - General requirements for the competence of testing and calibration laboratories. ISO.
[11] Wibowo P et al (2022) Comparisonal analysis study of power loss at the connection point of pierching connector with line tap connector on 220 V Low voltage network at PT. PLN (Persero) ULP Stabat. *INFOKUM*, *10*(03), 398-404.

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