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IoT and measurement of fermentation process of rice wine

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Abstract. The article deals with the fermentation process of rice wine and obtaining data during fermentation with the help of IoT, developed and implemented stirrer. Stirrer was printed by 3D printer. The process of converting D-glucose into ethanol together with the oxidation of reduced coenzymes is called fermentation. Ethanol fermentation takes place anaerobically, i.e., without access to air with the help of yeast. The fermentation process is gradually being improved with the help of acquired sensor data and the gradual possibility of automation. The main objective of this paper is to develop an experimental environment for measuring rice wine fermentation processes with the help of IoT. During the fermentation of rice wine, there are measurable attributes that can be measured with the help of sensors. These attributes affecting the final product quality, positively but also negatively (pH, temperature, humidity, etc.). It is therefore necessary to select a given sensor that can monitor the attributes and then devices that can then manage and evaluate it. the correct selection and use of sensors and computing equipment, the acquisition and processing of data and the application of the resulting values to fermentation procedures, the resulting product quality increases.

Key words: automation, IoT, fermentation, rice wine, sensors, ethanol.

INTRODUCTION

The development of industrial technologies nowadays is moving forward relatively quickly, and that is why sensorics can be applied to a wider extent in the food-agricultural complex. The IoT includes technologies that present themselves as a network of physical objects that are connected using the Internet and acquire data, then send them via the Internet to compute units that process them. It is a relatively demanding architecture, which must be properly designed, connected, and equipped with suitable sensors and devices for communicating with each other (Gilchrist, 2016).

Today, thanks to industrial technologies, the fermentation process can be monitored and tracked via programmed internet interfaces with the help of IoT. These measured data can then be processed and used in the food-agricultural complex for the subsequent improvement of processes and output products. In this case, to improve the resulting properties of fermented rice wine and thus minimize the resulting negative properties of the product (Lokman et al., 2020; Yang et al., 2020).

One of the main units in systems designed for IoT are the sensors themselves, external devices designed to measure and collect the required data. Subsequently, these measured data are stored on computing units that are connected to the internet, and then these data are sent to storage, such as the Linux server. The measured data are in the fermentation processes about temperature, humidity, acidity etc. Complete information about the fermentation process is obtained and processed continuously in the fermentation process. Subsequently, they can be processed for various applications that can run locally or be presented to the world of the internet with the help of web interfaces Tomtsis et al., 2016.

Fermentation is the process in which D-glucose $C_6H_{12}O_6$ is converted into C_2H_5OH ethanol along with the oxidation of reduced coenzymes (NADH - nicotinamide adenine dinucleotide (NAD) + hydrogen (H), FADH - flavin adenine dinucleotide + hydrogen (H)) - called fermentation (Slapkauskaite et al., 2019; Keot et al., 2020).

Overall, fermentation processes are very demanding regarding the technological process, especially to ensure the inaccessibility of air, as there is a risk of mold attack. To improve the fermentation process, the process of automation, i.e., the IoT industry, is also suitable. The design of an autonomous stirred made by 3D printer can also be applied here. To better mix the released substances into the solution during the fermentation process, it is also advisable to use a stirrer, which mixes the so-called dead spots during the fermentation process. The aim of this article was measure and compare data during fermentation process using a stirrer and without stirrer (Uehara et al., 2018; Cai, 2019).

Arduino and Raspberry Pi dominate today's market due to the wide range of possible applicability of various additional devices, ease of control, programmability, especially wide support in regional information technologies and, to a large extent, the popularity of the public thanks to relatively low acquisition costs. The Arduino platform is focused on the communication of devices via a serial bus, unlike the Raspberry Pi platform, which is currently able to communicate via the SPI, I2C, GPIO buses and has the function of a complete microcomputer. A Linux-type operating system named 'Raspbian' is installed on the Raspberry Pi microcomputer, in contrast to the Arduino computing unit, which does not have any operating system and an external operating system of another computing unit is needed to program the Arduino itself. Thus, Arduino can be programmed from the Raspberry Pi microcomputer, but it is no longer possible from the other side. These computing units can then be programmed in programming languages such as Java, Bash, Python, C and C++. These languages are suitable for the subsequent programming of computing units and the given sensors, which are suitable for the given solution due to the broad support of the publisher of these languages and, especially here, the very important support of the public. Today, on the Internet and various forums, it is possible to find a large amount of advice and information about the programming possibilities of these computing units, which to a large extent led to the achievement of the success of the problem being solved (Keot et al., 2020; Yang, 2020).

MATERIALS AND METHODS

To realize the fermentation process of rice wine, an experimental environment was designed and assembled in which the specified fermentation process took place under constant conditions for all fermented products in Fig. 1. Two fermentation vessels were equipped with an experimental self-contained stirrer, but already produced with the help of a 3D printer. In the remaining fermentation vessels, an experimental self-contained stirrer was not applied due to the possibility of comparing changes in fermentation processes compared to vessels with an applied experimental stirrer.

Before the actual implementation of the fermentation process and production of the autonomous mixer, information was obtained about the individual types of sensors that can be used in the fermentation process. Subsequently, they were acquired and applied to the fermentation process. A Raspberry Pi 4 model B 4GB RAM microcomputer was chosen as the main computing unit for the task of data collection and subsequent processing.

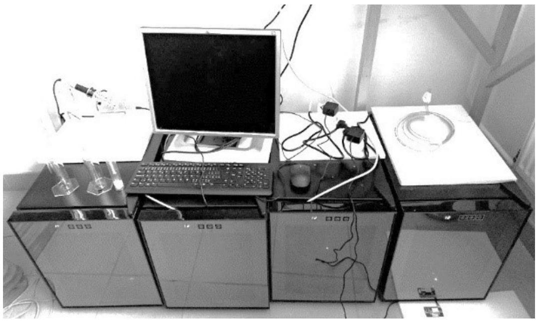

Figure 1. Experimental fermentation environment.

The first measurable attribute in rice wine fermentation was moisture, and this attribute was measured by the BMP-280. The program for this sensor was programmed using the Python language. Another well-measurable attribute is the temperature inside the container and the external temperature outside the container. For this purpose, the experimental environment was fitted with a DS18S20 sensor. The temperature sensor placed inside the container was made in a waterproof version and was placed directly in the solution. Another sensor that was also immersed in the solution was the E-201C-Bue solution pH probe, which was properly calibrated and programmed in C++. During the measurement, the sensors recorded data in time intervals of 120 seconds and then evaluated them as average values, which were automatically calculated by the program with the standard deviation of individual sensors in real time and recorded in a form for better clarity.

Before application, the water was boiled and then the specified amount of sugar was mixed into the boiled water at a temperature of 70 °C. Individual prepared solutions were mixed in one container with a volume of 20 L to obtain the same properties of the fermented solution. This was followed by gradual cooling of the solution to room temperature, which lasted 24 hours. Subsequently, the solution was applied to the individual fermentation vessels in the same amount along with the application of additional ingredients of oranges, lemon, rice and cloves (Fig. 2). The rice was also heat-treated prior to application by boiling and then cooling as a prepared fermentation solution. Before closing the fermentation vessels, Vinflora yeast 20 mL was applied to the individual solutions in the fermentation vessels and the created experimental stirrer printed on the Original Prusa i3 MK3S+ 3D

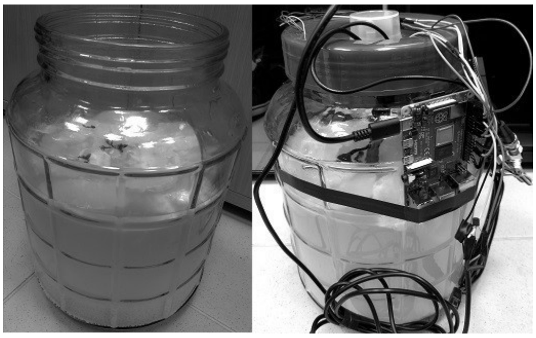

Figure 2. Vessels (from the left: Vessel with fermentation solution, vessels with sensors).

printer from Prusa Research was applied. As in the previous version of the independent experimental stirrer, the driving force of the CO_2 released during the fermentation of the applied solution was used here.

Autonomic stirrers made of three blades due to weight reduction friction compared to the four-blade variant. Every blade is 80 mm height, 37 mm width and 8 mm thick and form an angle of 42 degrees. The ends are rounded by R12,7 and the beginnings are welded to the rod ø 14 mm andin the middle, there is ø 8 mm bore for bar. The modeling of the experimental mixer itself, printed on a 3D printer, was realized in the Fusion 360 design program environment. After modeling the experimental mixer, it was necessary to export it to the.obj format, which is needed for the subsequent program for further modeling in the Prusa Slicer program (Fig. 3). In Prusa Slicer, it is necessary to modify the modeled model regarding the future filling with material, treat it with the progress of the printing simulation in the program against process failure. The program simulates future printing and looks for unwanted conditions that could be the cause of incorrect or error printing. If the program does not pass the print simulation, the error rate data is returned, and the user is then prompted to correct the undesirable conditions. Once the process of checking the simulated modeling and printing of the experimental stirrer was in order, the Prusa Slicer program exported the design to the.gcode format, which is typical for printing with a Prusa Research 3D print.

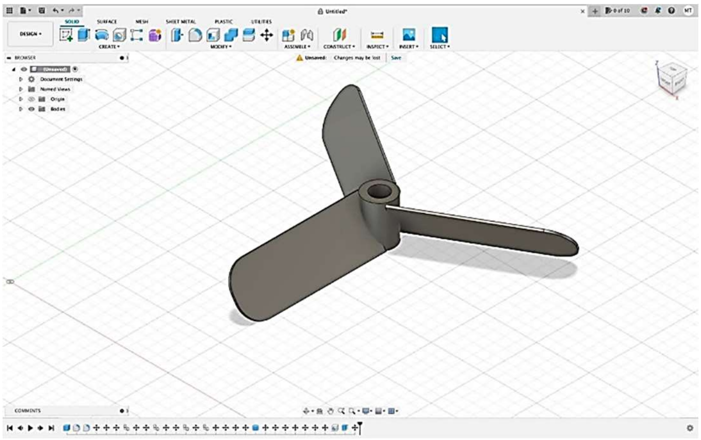

Figure 3. Part of autonomic stirrer printed by 3D printer.

RESULTS AND DISCUSSION

Heat is generated by the process of converting D-Glucose into the desired ethanol. The measured temperature before starting the fermentation process was, as in the previous project, 21 °C to obtain the most accurate results. During vigorous fermentation, i.e., when the highest amount of conversion of D-glucose by the yeast into ethanol occurs, lower temperature values were measured in vessels with a stirrer compared to fermentation vessels without a stirrer in the order of 2 °C. Later, after vigorous fermentation, the fermented solution began to gradually cool down due to the gradually decreasing activity of the yeast.

Following the end of the yeast fermentation process, consumption of D-glucose, the fermented solution was subsequently cooled to a constant temperature of 12 °C, corresponding to the previous project (Fig. 4). The temperature was subsequently maintained by cooling boxes (with thermoregulation) at the mentioned temperature. The highest temperature reached during the fermentation process was 29.9 °C in the vessel without a stirrer on day 4, and 29.7 °C in the vessel with the experimental stirrer on day 5. The rise in temperature in containers without a stirrer is higher during vigorous fermentation than in containers with a stirrer, but after vigorous fermentation, the solution cools down faster in containers without a stirrer than in containers with a stirrer.

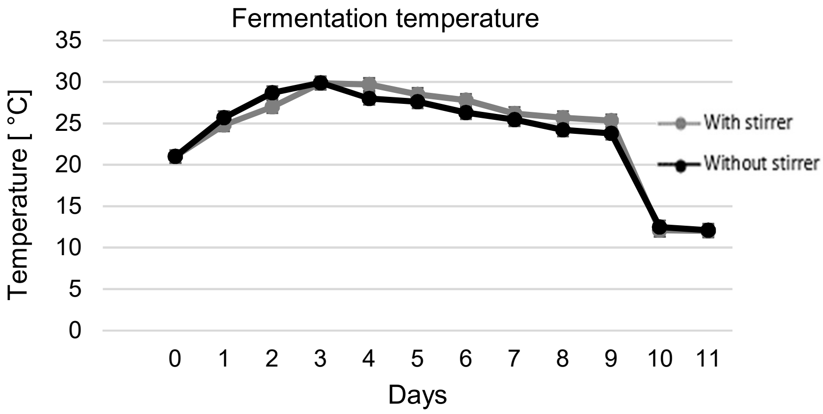

Figure 4. The course of fermentation temperature.

The next well-measurable quantity during the fermentation process is the humidity in the fermentation vessels. The measured values in the same conditions as in the previous project were an average of 85% with a 5% deviation in all the containers measured by the sensors. The percentage moisture during vigorous fermentation was 4.7 °C higher in the container with the fermented solution without a stirrer on the first day than in the container with the experimental 3D printed stirrer. The trend of higher percentage moisture in the containers without a stirrer was maintained until the 5th day of the fermentation process, when the vigorous fermentation process was completed and from this point there was a gradual decrease in percentage humidity.

Subsequently, the trend was reversed and the vessel with the stirrer held a higher percentage of moisture compared to the vessel without the experimental 3D printed stirrer (Fig. 5). Subsequently, after the cooling of the fermented solution by placing it in the cooling boxes, i.e., the end of the overall fermentation process, the resulting value of percentage humidity stabilized at the original value of around 85% with a minimal deviation, since the cooling was regulated by the cooling box to a temperature of 12 °C.

The last, well-measurable aspect is the pH value, or the acidity of the fermented solution, which is indicated by the hydrogen exponent. The initial pH was measured to be 7.28 before fermentation started. As a result of the gradual conversion of D-Glucose into the desired ethanol by yeast, the pH value in the fermented solution decreases, i.e., the acidity of the solution increases (Fig. 6). Throughout the fermentation of the solution, as in the previous measurement, the solution with the experimental self-sustaining stirrer showed lower pH values compared to the containers with solution, in which the experimental spontaneous stirrer was not applied. However, there was now a lower dispersion of values between these fitted and unfitted vessels with an experimental stirrer compared to the last measurement, in the order of hundreds to tenths of units of the pH hydrogen exponent.

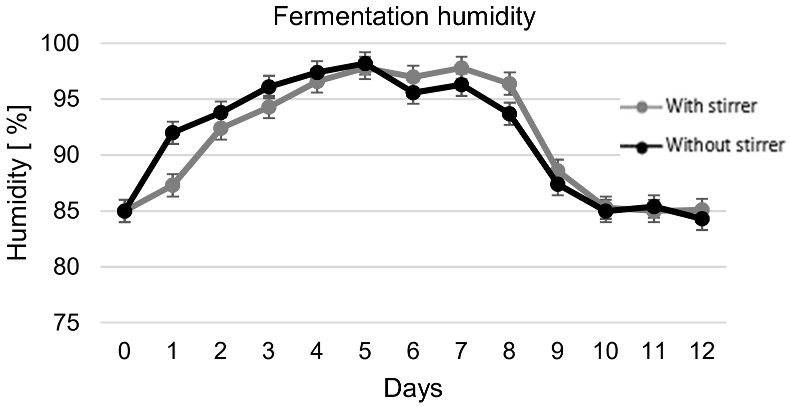

Figure 5. The course of fermentation humidity.

The research done by Latayan states that the rice wine product was created should contain a minimum limit of 4.0 pH and a maximum of 4.5 pH (Latayan, 2002).

It is practically contradicted by Lee et al., in that in their research they report pH values for the resulting rice wine product of 3.4 pH values to 4.5 pH values (Lee et al., 2007). In further research, Jin et al., Leo et al., reported lower pH values caused by a higher acid content in the solution. In our case, it can be caused by the acid content by the inclusion of additional aspects, a different variety of rice, as well as different fermentation cultures (Jin et al., 2008).

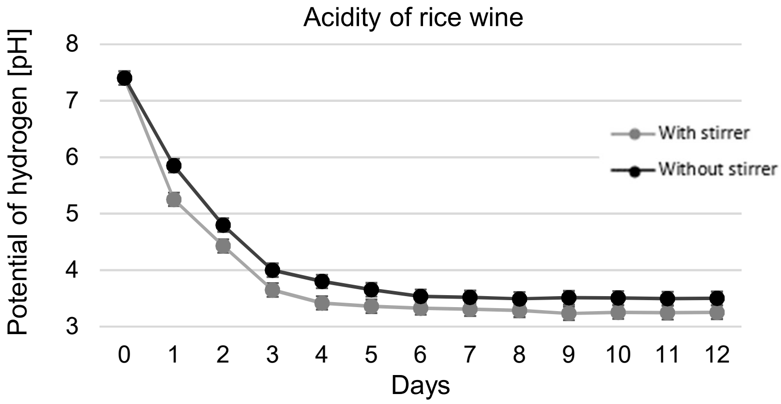

Figure 6. The course of fermentation acidity.

The measured temperature values in the work were lower compared to the research conducted by Liu et al. Especially in exponential fermentation. Liu et al. report that for rice wine fermentation, the highest temperature rose to 31.9 °C. In both cases of measurement, the highest temperatures were maximum around 30 °C. This phenomenon in Liu et al. can be attributed, for example, to a higher sugar content in the fermented solution, as the yeast has more resources for reproduction and subsequent greater production of ethanol, which generates heat. This applies to vessels without experimental stirrers (Liu et al., 2016).

CONCLUSIONS

The resulting values of the obtained data during measurement achieve matching continuous properties as measured data. Confirmation of the finding that the application of experimental stirrers affects, albeit in some cases minimally, the ongoing and final properties of fermented rice wine.

The moisture percentages are higher in the vessels without the applied experimental stirrer in the vessels during the rampant fermentation process. After the vigorous fermentation process, the opposite effect occurs, with the vessels with the experimental stirrer reaching higher continuous values.

In both cases, however, the percentage of alcohol met the criteria for the percentage of alcohol content in rice wine (lower limits). With a higher amount of initial sugar content in the solution, the resulting alcohol value would be higher.

In vessels without an experimental stirrer, the value of both the continuous and the final pH was higher than in the vessels with an experimental stirrer printed on a 3D printer. The resulting pH value is desirable at lower values, as it indicates a better mixing of the individual ingredients into the solution.

The measured values, i.e. in the container without a stirrer 3.24 pH and in the containers with a stirrer produced with the help of 3D printing, this value was stabilized at a value of 3.1 pH. However, the resulting pH values of the obtained rice wine fall within the pH value standards for this product.

Therefore, it was found that experimental stirrers influence the course of practically all measured aspects. In some cases, this effect is minimal, in some cases more striking. In particular, by helping to release additional ingredients into the fermented solution.

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