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Measurability of quality in fermentation process of rice wine by IoT in the field of industry 4.0

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Abstract. The article inquiries into the issue of automation of the rice wine fermentation process in the field of industry 4.0. Fermentation is the process of converting D-glucose into ethanol along with oxidation of reduced coenzymes (fermentation). This is known as ethanol fermentation, which takes place anaerobically in the presence of yeast. The fermentation is being improved by automation (sensors, etc.). The main aim is to develop an experimental automation environment in industry 4.0 for the process of rice wine fermentation. During the rice wine fermentation process, variety of measurable attributes are created which affect the quality of the resulting product. They can be monitored with the help of automation elements (pH, temperature, humidity etc.). In case of an experimental environment development, it is therefore important to select appropriately the sensory that can record the measurable attributes. At the same time, the sensory must be at a level of reliability that guarantee their sufficient use in the mentioned experimental environment for the rice wine fermentation. The result is that, if the right environment is chosen, the quality of the fermented wine will improve.

Key words: automation, industry, 4.0, IoT, fermentation, rice wine.

INTRODUCTION

Nowadays, thanks to the development of industrial technologies, these technologies can be applied extensively in an agri-food complex. The technologies, at present, include industry 4.0, especially the Internet of Things (IoT). The Internet of things (IoT) describes the network of physical objects that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet. Industry 4.0 is the information-intensive transformation of manufacturing (and related industries) in a connected environment of big data, people, processes, services, systems and IoT-enabled industrial assets with the generation, leverage and utilization of actionable data and information as a way and means to realize smart industry and ecosystems of industrial innovation and collaboration. In the fermentation process of rice wine, technologies including standard 4.0 can be used for data acquisition. During the fermentation process, substances, that can be monitored with the help of sensors, are produced. These substances have a significant effect on the sequent quality of the resulting product and can therefore lead to an improvement or deterioration of quality (Gilchrist, 2016).

The measured values can be interpreted via the Internet interface using IoT and the fermentation process can be virtually monitored online. Especially for collecting measured values to one place like server, PC or data storage. The measured values in the agri-food result of the complex can be used to improve the fermentation process. Thus, the possibility of deterioration of the quality of the resulting product will be minimized (Lokman et al., 2020).

Especially IoT in the fermentation process can be found as external device for measuring and collecting data from sensors. Storing data and this device can be connected to the internet for sending data to storage like external server. Measured data in fermentation process are usually about temperature, humidity, acidity etc. They are measured usually throughout the fermentation process for getting the whole information about fermentation process. Data can be throughout the fermentation process processed and presented on website or in application for better overview about fermentation process (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, FADH) - called fermentation. It is an alcohol fermentation (ethanol). Fermentation takes place anaerobically (under inaccessible air) and energy that is stored in ATP adenosine triphosphate molecules is being released. If the D-glucose $C_6H_{12}O_6$ is by chemical processes converted into ethanol C_2H_5OH and carbon dioxide CO_2, the alcohol fermentation takes place. This happens in the presence of yeast (Keot et al., 2020).

Any fermentation processes are greatly technologically demanding. Even the slightest mistake can completely devalue the resulting product. The fermentation can be expressed by chemical formula: $C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$. The fermentation is also further improved by automation, which greatly helps to improve the production process, quality of the product, simplifying work and mainly the quantitative production. It also substitutes the work of man and thus minimizes the error rate of production caused by human error such as autonomic stainless-steel stirrer (Uehara, 2018).

The stirrers help in the fermentation process to better mix the substances that they gradually release during the fermentation process and to mix the dead spots. During the fermentation process, carbon dioxide was released, which is driving force to rotate the stainless-steel stirrer and mix releasing substances on its own (Cai, 2019).

Fermentation process also can be found in different fermentation environments such as milk fermentation, soya fermentation by lactic acid bacteria, vegetable and fruit fermentation and mainly in mentioned fermentation, where is goal to obtain alcohol drink (wine, whisky etc.). With combination with IoT, these processes can be improved. Mainly for getting data, from places where is not great internet connection (Slapkauskaite et al., 2019; Yang et al., 2020).

MATERIALS AND METHODS

The following experimental fermentation environment was established (Fig. 1). As the environment, in which the fermentation took place, was chosen a glass 9 liters fermentation vessel from Orion. A total of 4 vessels were used for the fermentation, two containers were without the self-stir and two containers with an autonomic stainless-steel stirrer. The resulting measured values are processed as average values. Two vessels without stirrer, represent the grey line and two vessels with stirrer represent black line in the par of results and discussion.

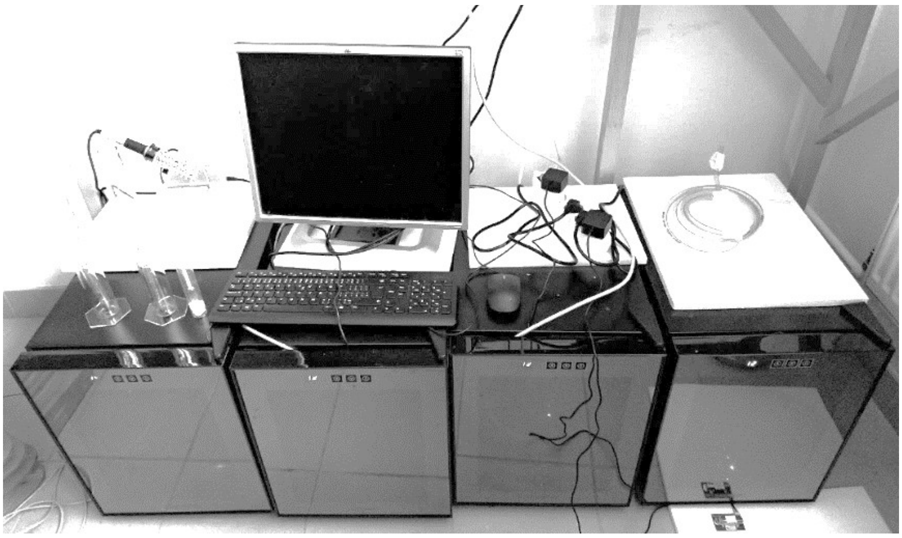

Figure 1. Experimental fermentation environment.

A fermentation solution of rice wine was implemented into this container in the following way - the solution contained 5l of water, 1kg of sugar, 1 kg of rice, 500 g of orange, 200 g of lemon, 5 pcs cloves. The water was boiled. After the overcooking, the sugar was poured in warm water for better distribution. This solution was mixed in one 30 L container to obtain the same fermentation conditions. Subsequently it was cooled to a room temperature for 24 hours. After that, the solution was poured into individual fermentation vessels together with the addition of the individual listed items.

The rice was overcooked before being put into the fermentation solution. Prior to closing the fermentation process in individual containers, Vinflora ® 20 mL yeast was poured directly into the prepared solution. Finally, the vessels were closed, the fermentation lids were fitted, and the fermentation process took place (Uehara, 2018).

Autonomic stirrer made of stainless-steel (ČSN 17240. AISI 304 in the Czech Republic) was modeled in a software SOLIDWORKS environment which is suitable for this purpose (Fig. 2). Subsequently, it was

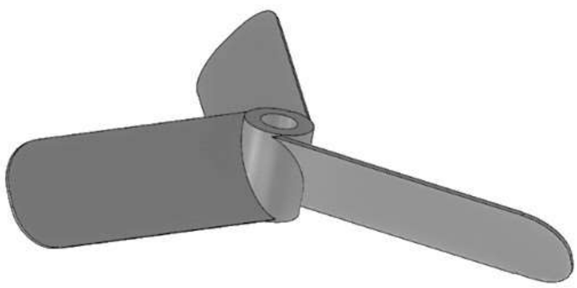

Figure 2. Part of autonomic food stainless-steel stirrer.

cut, machined, welded, fitted, and applied in two fermentation vessels. Autonomic stirrer is 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. The ends are rounded by R12,7 and the beginnings are welded to the stainless-steel rod ø 14 mm and in the middle there is ø 8 mm bore for bar.

Before the implementation of the fermentation process, sensory technology was selected and applied on the fermentation vessels. Raspberry Pi 4 model B 4GB RAM (4 units) serves as the main calculation unit, which is responsible for the communication and data collection throughout the proposed system from sensory in the process of rice wine fermentation. For the correct gathering of information from individual sensors, it was necessary to properly install the connectors, solder the required electrical components and last but not least to program the sensors in the Python and C++ programming language. The whole system is working on the operating system of the latest Raspbian (Linux) update (Fig. 3).

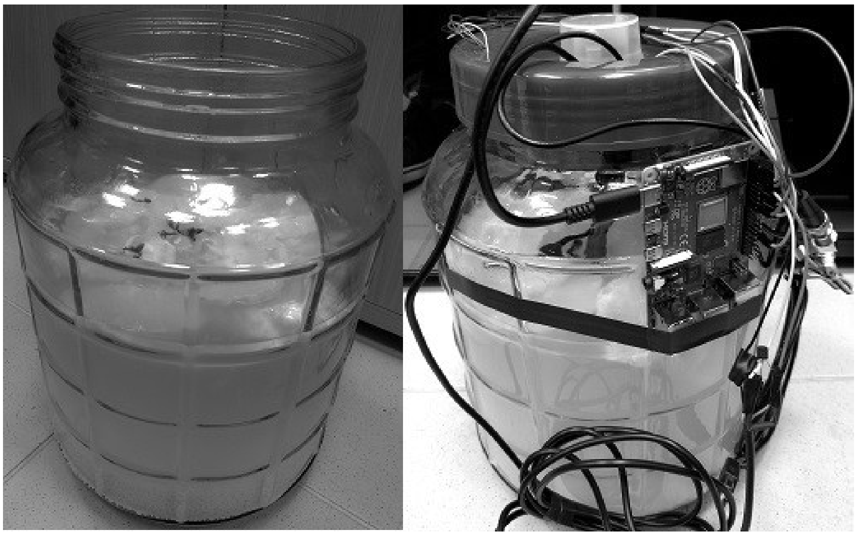

Figure 3. Vessels (from the left: Vessel with fermentation solution, vessels with sensors).

The first component that primarily measures humidity is called the BMP-280. It uses the I2C interface on Raspberry Pi 4 model B 4GB RAM programmed in Python. The measurement of the temperature both inside and outside the container in the cooling box was carried out with the help of the DS18S20 sensor. DS18S20, which was placed from inside the container was immersed in the solution. This sensor must have been in a waterproof version. Sensing of this sensor is realized in the C++ program. The third sensor that was placed in the solution was the pH probe E-201C-Blue, which was properly calibrated and programmed in C++. Data collection by the compute unit took place every 60 seconds and the data was stored in internal storage and after that externally processed (Fig. 3).

In such manned containers with sensors and prepared process for fermentation, they were placed into the cooling boxes HYUNDAI VIN12A HYUVIN12A. At the end of the fermentation process, the solution was cooled to 12 °C. During the fermentation, the sugar content of the solution was also measured using a sugar meter and the percentage of alcohol contained in the fermented solution with an alcohol meter.

RESULTS AND DISCUSSION

The first best measurable attribute is the temperature inside the vessel, which fermentation generates spontaneously by conversion of glucose especially into alcohol. The room temperature at the beginning of fermentation was 21 °C (Fig. 4). The fermentation vessels that do not contain an automatic stainless-steel stirrer have a higher temperature during the fermentation process of rice wine literally throughout the whole process. After the 8th day of fermentation, i.e., after the end of the fermentation, the solution was in cooling boxes cooled to 12 °C and this temperature was constantly maintained. The highest temperature achieved during the fermentation was 30.9 °C in the container without the stirrer and 29.7 °C in the container without the stirrer. Thus, the tendency of the fermentation temperature is rising more slightly in vessels with a self-stirring stainless-steel stirrer than in vessels without self-stirring stirrer.

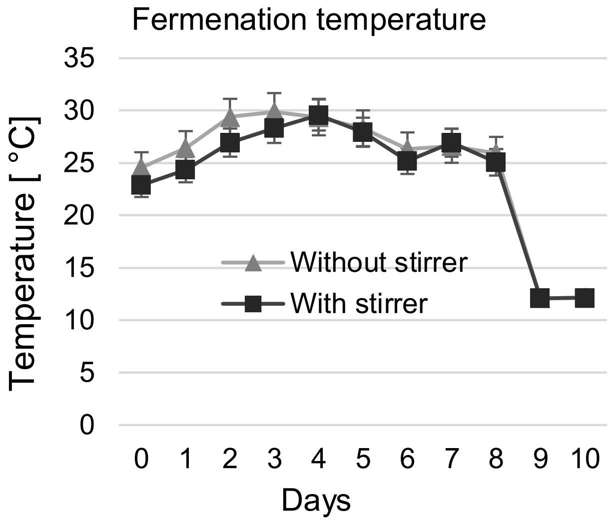

Figure 4. The course of fermentation temperature.

Another interesting and well-measurable attribute is the percentage humidity in individual containers. After closing the vessels and before starting the fermentation process, the moisture value of the vessel was on average 85% (Fig. 5).

Consequently, the percentage humidity initially during fermentation was higher in fermentation vessels without a spontaneous stirrer made of stainless food steel due to the faster onset of the yeast fermentation process. Both trends were increasing. However, the fermentation with stainless steel stirrer was slower but there was the highest humidity of 98.4% in the vessel with stainless steel stirrer vs. 97.3% in vessel without stirrer.

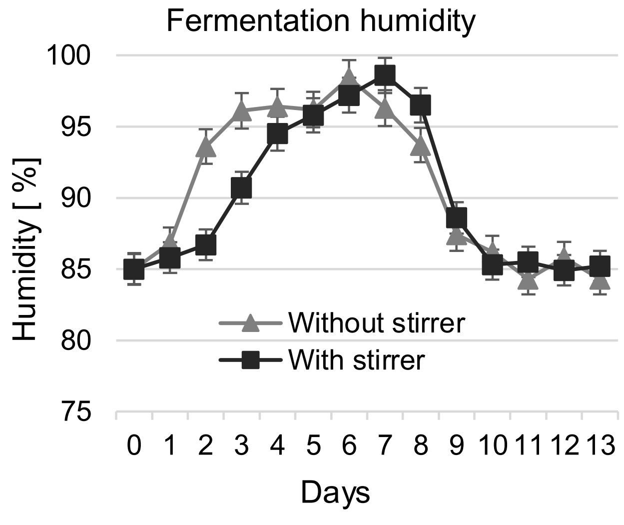

Figure 5. The course of fermentation humidity.

The third measurable aspect was acidity measurement (pH). At the beginning, the pH of the water itself was 7.4 ph. After the overcooking, adding sugar and further ingredients, it was 5.35 ph. (Fig. 6). During the process of fermentation of rice wine pH significantly decreases due to the consumption of continuous nutrients of yeast and the production of alcohol. The resulting pH was lower in containers with a self-stirrer than in containers without a self-stirrer.x

In the fourth case, the percentage of sugar content of fermented rice wine, was measured. The basic solution contained 23.5% sugar content. The decrease of percentage of sugar content was monitored in the fermentation process that was conducted in a container without a stainless-steel stirrer. In the container with the stainless-steel stirrer the consumption of sugar was slightly slower. Between the third and sixth day, the highest consumption of the sugar was measured (Fig. 7). That was the peak of exuberant fermentation. After the ninth day, the percentage of sugar content in the solution was 0% meaning there was no longer a fermentation process going on.

The fifth aspect measured was the percentage of alcohol in the fermented rice wine solution. The conversion of sugar by yeast into alcohol is proportional and therefore there is an increasing tendency. After consuming of all the sugar in the solution, the percentage of alcohol in the solution was 13,5 % in a container without a stirrer and 12,8 % in a container with a stirrer (Fig. 8). The alcohol level of regular rice wine varies in different 12-25% alcohol, so this rice wine affects the lower limit range.

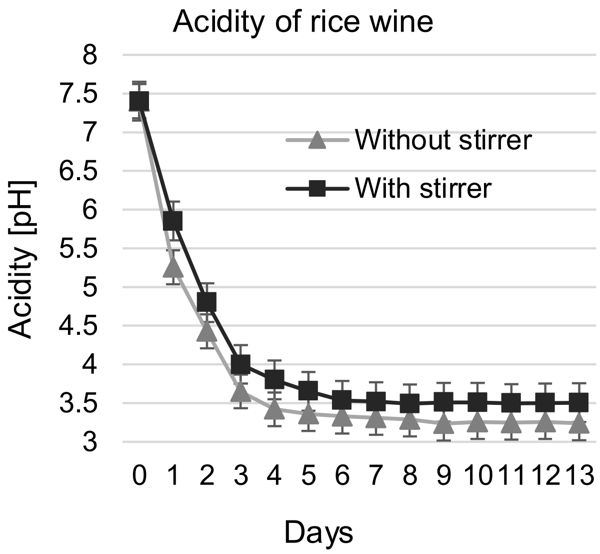

Figure 6. The course of fermentation acidity.

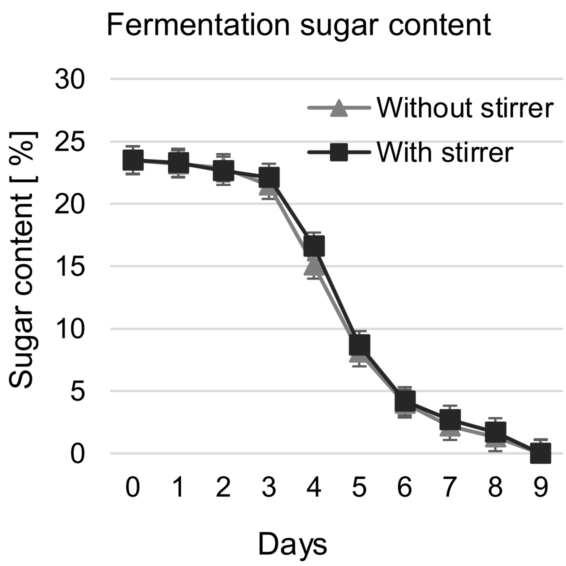

Figure 7. The course of fermentation sugar content.

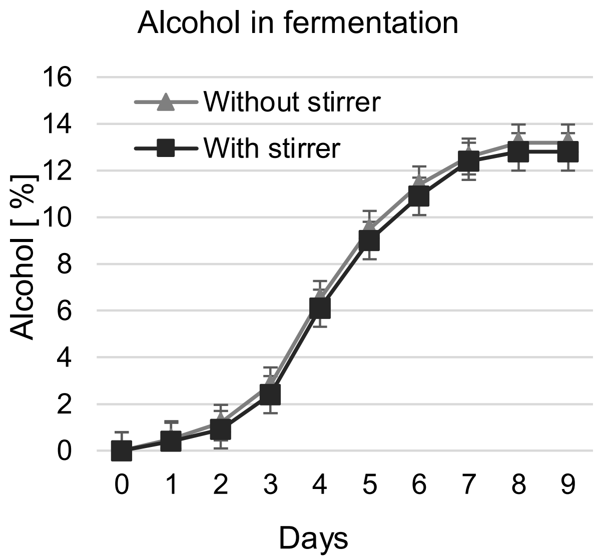

Figure 8. The course of alcohol content.

CONCLUSIONS

The use of a stainless-steel self-stir affects the fermentation process. The temperature is affected. The temperature increases slower during the fermentation in containers with a stirrer than in containers without a stirrer, where the temperature increase is faster. The percentage humidity in the container has the same tendencies as the temperature, i.e., without the stirrer it has a faster increase than with the stirrer.

The self-stir most significantly affects the pH since the substances are better released from additives to solution in containers with a stirrer than in containers without a self-free stainless-steel stirrer. This also slightly influences the conversion of sugars into alcohol. Here, in containers with stainless steel stirrer, the transformation tends to be more gradual than in containers without a stirrer.

For the future, subsequent improvements in the shape of stainless-steel self-stirs scoops and replacement of the material with e.g., plastic suitable for the food industry with the help of a 3D printer will probably make it possible to achieve greater efficiency in the release of substances from additives into fermented rice wine.

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