CASE STUDY OF AUTOMATION OF A PUBLIC SOYA MILK FACTORY

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Abstract. *This work presents the case study of the automation solution of a public soya milk factory, originally implemented in a non-automated way by the city of Extrema (Brazil). Being a public factory, it does not aim any profit and its objective is solely providing soya milk to public schools in the city of Extrema. The factory is modeled and, through simulation, the best set of operational parameters is determined, concerning productivity, cost, and maintenance. Considering the simulated results, automated modules are proposed in each part of the production process, in order to facilitate implementation and reduce initial investment. The modules are composed of acquisition, control and supervision systems, and can communicate to each other. The result is a cost effective automated system that handles I/O parameters, integrating the whole production plant in a closed circuit, monitored by a supervisory software.*

Keywords*: automation, continuous systems, soya milk production, supervisory devices*

1. INTRODUCTION

Automation can be defined as a “system of electro-electronic and/or mechanic equipments” that has self control, almost without human supervision. As a consequence, automation allows the work of automatically controlled machines. The automatic control systems can be easily found in sectors of industry such as quality control (failure detection and product discharge) and product manufacturing, automatic assembling, tooling control, space and weapon technology, transport systems, power systems and others (Silveira and Santos, 2002).

Hence, looking at the day-by-day of industrial continuous production, the variations that occur can be measured and analyzed, focusing on its impact in the final product quality. However, in an automated process, these variations are reduced to a narrow tolerance margin called “control limit”, being the variation a consequence of the direct influence of the adopted instruments and work conditions. Automation systems basically have four fundamental components: sensors or transducers, actuators, comparators, and controllers.

There are companies in the market that provide full developed projects in processing soya milk, which use automatic modules in integrated and independent production systems for each stage of the process. The objective of this work is the simulation of the automatic process of the soya milk factory located in the city of Extrema, MG, Brazil. The simulation is done from the soya milling stage up to the pre-cooling to ambient temperature, through use of a LPC (Logical Programming Computer) and a HMI (human-machine interface). The supervisory system simulates the transitions among the process stages in study, for posterior implementation as a function of the obtained results.

2. SOYA MILK FACTORY

2.1. The Soya Milk

The soya bean (Fig.1) is considered an excellent source of proteins for human breeding and can be processed in grains, milk, cheese, etc. The soya milk and dairies have higher energetic and protein values than cow milk, but it cannot replace completely the cow milk (Mesquita, 2001). The nutritional value of soya can be limited, partly because of the presence of undesirable components called anti-nutritional factors, which include digestive enzyme inhibitors, fenolic components, and non digestible carbohydrates like rafinose (sugar crystals found in vegetable cells). However, soya can be considered a functional food due to its high quantities of flavonoids (anti-oxide and strogenic substances – MecBrasil, 2005)

Figure 1 – Soya bean in grains (Embrasoy, 2003)

The soya milk can be mixed to fruits or flavors that result in a variety of tastes (orange, strawberry, pineapple, banana, peach, papaya, apple, chocolate, pear, corn), turning the product much more attractive and tasteful for kids and grown ups. Due to the possibility of flavor variation with fruit addition, the soya milk can be used as a nutritional complement besides its natural protein source and vitamins. The milk is recommended to all ages, from younglings to elder people, including pregnant women, and is an alternative to people that have problems of digesting lactose (protein found in animal milk). The soya milk is also rich in fibers, being an excellent therapeutic food preventing and treating diseases like diabetes, heart diseases, and cancer of colon, rectum, stomach, prostate and lung. Excellent results are also reported in patients with hypertension, high cholesterol and kidney diseases. It can be found in soya dairies, specially in milk and juice, the isoflavone substance (natural hormone), which together with a healthy day life can prevent some sorts of cancer such as breast and ovary in women. It also helps preventing and retarding osteoporosis and alleviates the symptoms of menopause (Embrasoy, 2003).

The implantation of industry with appropriated technology of soya dairy for human breeding is the way of introducing the mentioned grain into the Brazilian diet, mainly in regions where there is a remarkable lack of protein, like in the rural areas or among the poorer people in the margins of big cities (MecBrasil, 2005).

2.2. Automation of Product and Process

An automatic system is that one whose result is previously defined and the system tries to reach it without the interference of an operator. A rigid automated system is that one whose control is automatic, however it allows alterations of the process after defining the system itself and its components. A flexible automated system is that one which allows the alteration of the system and its components, such as excluding inputs and outputs, logical programming, blocks, etc (Borges *et al.*, 2000).

The sensor or transducer is a device able to measure a property of the automated system. The actuator is a device that sources energy to the system aiming at reaching a desired objective (these components belong to the controlled process). The comparator compares the measured values to those pre-defined, giving information to the controller. The controller uses the information provided by the comparator, taking decisions of how and when actuating on the system, by means of the actuator.

2.3. The Soya Milk Manufacturing Process

The production of soya milk can be improved regarding supervision quality and data controlling with higher precision. The plant in study has materials and methods which have been implemented and are under continuous operation for more than 10 years. Because of that, there is an opportunity to improve the system by adapting the materials to the new methodology of study.

The manufacturing process of soya milk (target of this work) is described based on the process stages. Figure 2 presents the flowchart of the non automated process. The implementation of automated control will not focus on peeling, cooling and packing. Hence, from the point of view of automation implementation, the process begins at Milling with Hot Hydration and ends at Pre-Cooling.

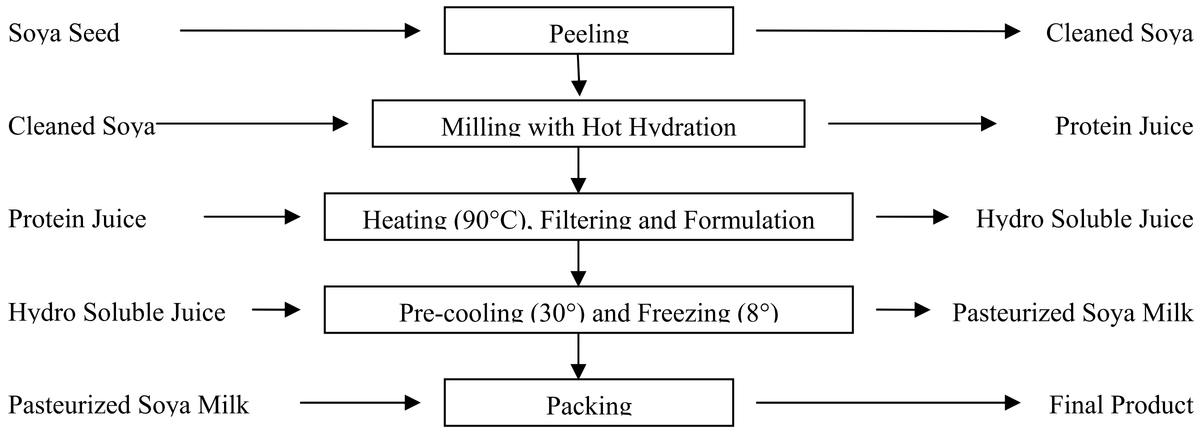
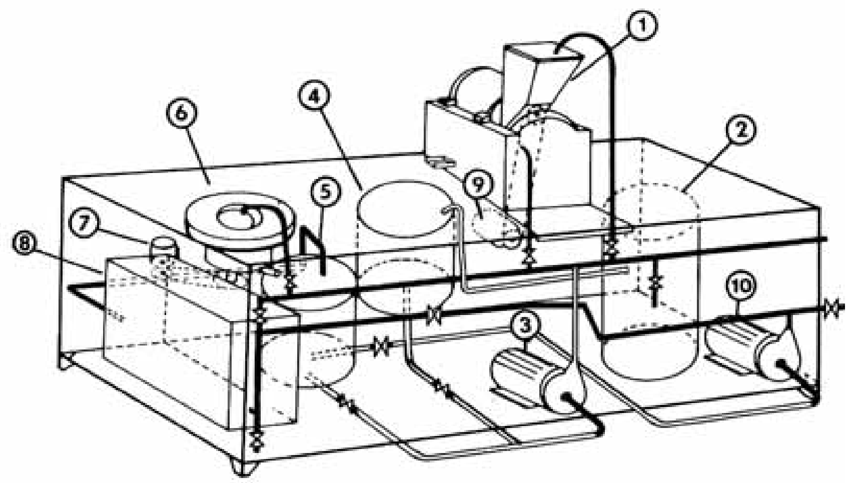


Figura 2. Flowchart of the manufacturing process of soya milk (non automated).

The pasteurization process is an important stage in order to reduce the number of microorganisms in liquids, thus enhancing storage time, as shown in Tab. 1. First, the process will be controlled without improving the process. The process could be improved by optimizing the heating and cooling time (thermal treatment), but this is not the objective of this part of the work, and the process improvement can be done by a future analysis of cost and benefit. Figure 3 presents all equipment of the mechanic cow (soya milk machine) which exists in the city of Extrema (Brazil). Figure 4 presents the real factory of soya milk, including the final independent stages (11 and 12).

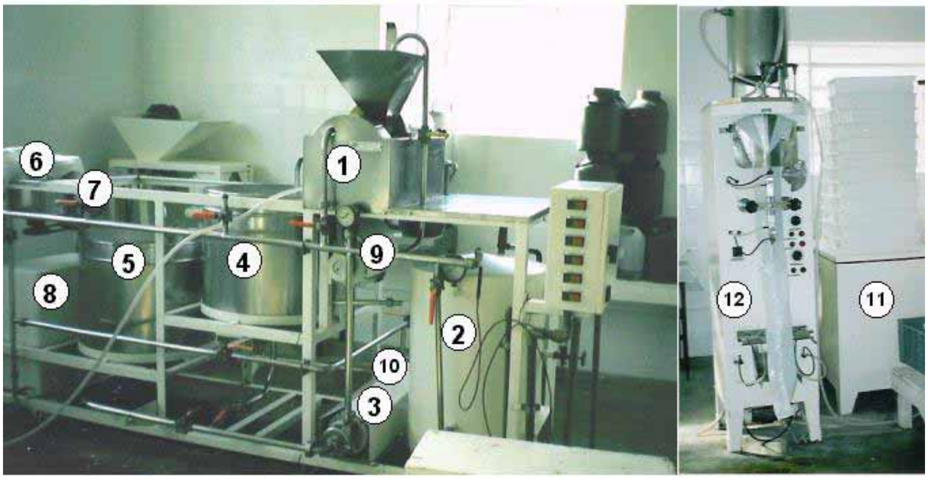
Table 1. Soya milk validity time stored at 3ºC (Behmer, 1984)

Condition	Storage Temperature	Validity (days)
Without pasteurization	3ºC	1
With pasteurization	3ºC	5



1. Extractor
2. Heater (boiler)
3. Circulation pump 1
4. Tank 1 (processing)
5. Tank 2 (holding)
6. Centrifuge
7. Motor 1HP 4 poles (centrifuge)
8. Pre-cooler
9. Motor 3HP 4 poles (miller)
10. Circulation pump 2

Figure 3. Equipment of the mechanic cow (soya milk machine) in study.



1) Extractor
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7) Motor 1HP 4 poles (centrifuge)
8) Pre-cooler
9) Motor 3HP 4 poles (miler)
10) Circulation pump 2
11) Freezer (independent)
12) Packer (independent)

Figure 4. Equipaments of the existing soya bean factory.

2.3.1. Milling with Hot Hydration

One hundred liters of filtered water are supplied to tank 1 (processing tank) of the factory, being turned on the circulation pump 1 and opened the valves for cycle work between tank 1 and the boiler, till the water reaches a temperature of 90°C.

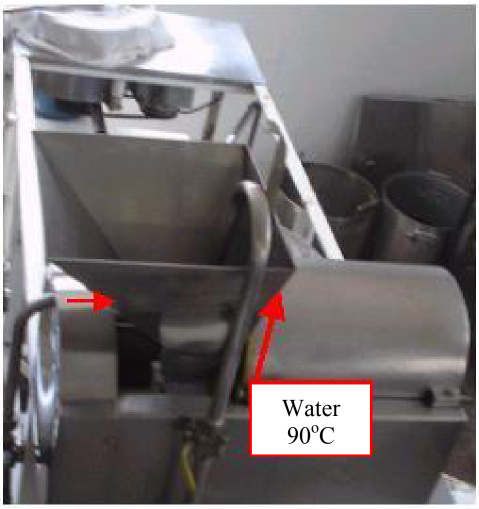

Figure 5. Soya miller.

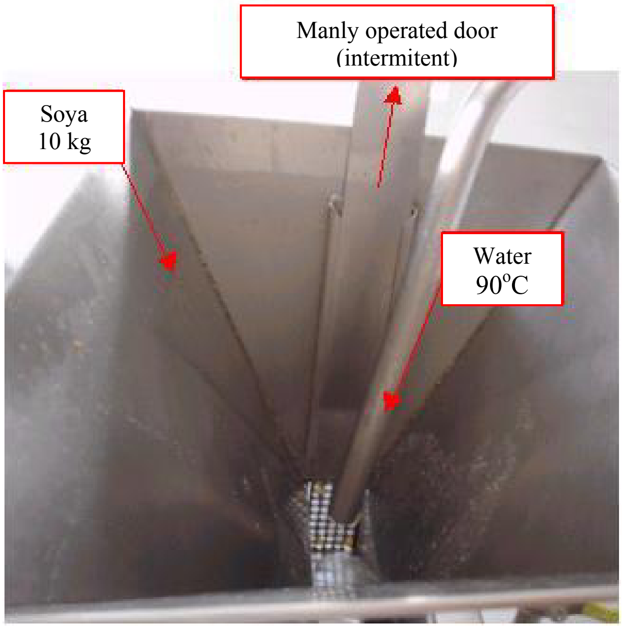

Figure 6. Soya grain reservoir.

The cleaned and peeled soya is handily supplied to the milling unit, shown in Figures 5 to 7, which have two water inputs for soya hydration and enzymatic pre-activation together with the milling process at temperature of 90°C. In this moment, the valves that control water flow to the miller are opened and the miller motor is turned on. Thus, the soya protein juice is pumped to the processing tank. The circulation pump 1 remains turned on, and the grain feeding valve is operated by hand. This operation is concluded after 10 kg of soya is processed, resulting in 100 liters of soya milk. The heating stage and opening of the grain feeding valve are not focused on by this work due to the limitation of tags that the simulation software can use. During the process, the product is transported to the processing tank, boiler and miller. The boiler is the actuator for monitoring the system temperature, and a termocouple is the temperature sensor, shown in Fig. 8.

The hot hydration has the objective of forming bitter and adstringent components in the soya milk due to the action of the lipooxigenase enzymes. In the case that dry grain peeling is not done, one can cook the grains for 20 minutes in boiling water for maximum water absorption and softening (1 kg of soya absorbs approximately 1.3 kg of water). In these conditions, the peel naturally looses, resulting in a cleaned grain that is ready to mill. This process cannot exceed 4 hours because the number of microorganisms begins to jeopardize grain quality and processing (Mesquita, 2001).

Figure 7. Blades of the soya miller.

Figure 8. Termocouple installed in the boiler.

2.3.2. Heating, Filtering and Formulation

After milling the grains, the product is heated; the valves in the miller input are closed, the circulation pump 1 remains turned on; and the product fills tank 1 and boiler until the temperature reaches 90°C, remaining at this temperature during 15 minutes. This heating process has the objective of inhibiting the action of enzymes that would have activity otherwise (below 80°C), since they have thermo resistance.

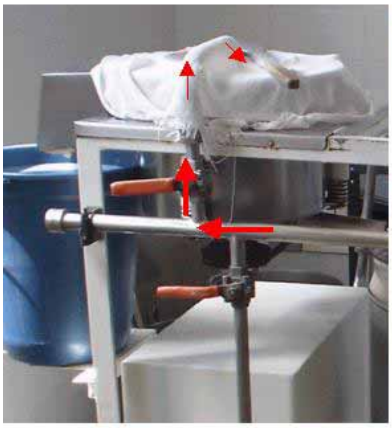

Figure 9. Product filtering.

Figure 10. Filtering output to tank 2.

After heating, the soya protein juice is moved to the filter where the juice is separated from the soya solid mass through centrifugation (Figures 9 and 10). The valves of the previous stages are closed and the valves for product flow are open to liberate the content to the filter. The circulation pump 1 remains turned on and the centrifuge motor is started up. After filtration, one has the hydro soluble soya juice, which is transported to tank 2. In this stage, the product must have a temperature of 85°C.

Figure 11. Filter condition after operation.

Figure 12. Soya protein residues in the filter.

Figures 11 and 12 present the filter after processing. Filtration occurs to separate the liquid soya milk from the soya solid pulp mass (Mesquita, 2001). After filtering, the liquid is sent to holding tank 2, where the formulation happens, and the flavor ingredients, sugar and color are dosed and mixed. During the formulation stage, the product remains cycling between the filter and the tank, with circulation pump 1 turned on. The indication of a good filtration is the absence of insoluble particles in the soya milk, and a humidity below 40% in the solid pulp mass (Mesquita, 2001). After formulation stage, the product is ready for pre-cooling (thermal treatment).

2.3.3. Pré-Cooling

In this stage begins the pasteurization process with thermal treatment. After remaining at the temperature of 90^{o}C during 15 minutes and pre-cooling to 30^{o}C, there is a slow pasteurization up to the temperature of 8^{o}C.

Figure 13. Inlet of the heat exchanger.

Figure 14. Outlet of product to tank 2.

This is the last stage to be automated, which is described by product pumping to the heat exchanger. In the pre-cooling process, the product is cooled from the temperature of filtering to 30^{o}C, by a heat exchange with water at ambient temperature. One opens the valve to direct the product flow to the cycle of pump 2, heat exchanger and tank 2. The valves of the previous stages are closed, circulation pump 1 is turned off and circulation pump 2 is turned on. Figures 13 and 14 show the shielded heat exchanger.

2.3.4. Freezing and Packing

This two stages of the process are included in the work as an illustration of the whole complete manufacturing circuit, which can be analyzed in the future as potential areas of automation. After reaching the ambient temperature, the milk is conducted to the freezer. In the freezer, the product is cooled through a radiator from 30^{o} to 8^{o}C, becoming ready for packing.

Figures 15 and 16 shown the product flow up to the final stages. In this stage, the valves of the previous cycle are closed, and the outlet valve is open, letting the product to flow to the packaging machine, remaining pump 2 turned on until all product content is packed.

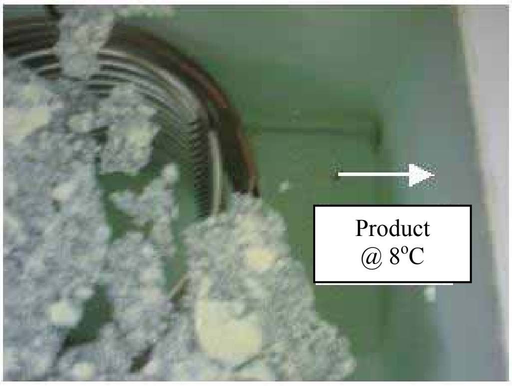

Figure 15. Product outlet for packing.

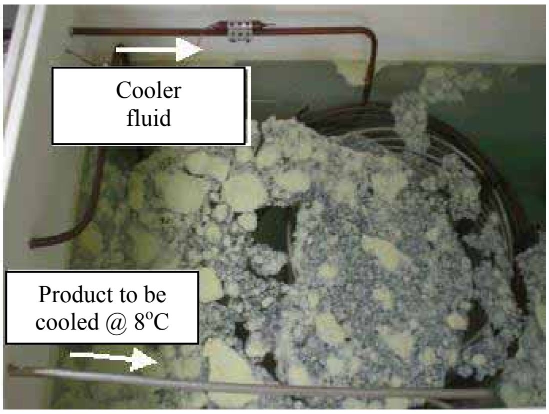

Figure 16. Cooler fluid and serpentine in the freezer.

The freezing process of the product is also a fundamental stage in the soya milk manufacturing because this is a highly degradable product and it demands a microbiological quality control. The product must be delivered right after production (Schexnayder, 1991). The product is finally packed without manual contact. The packing equipment is automated with pneumatic and inductance actuators, and are easy to operate and clean.

All equipment in contact to the product are made of stainless materials.

3. CONTROL SYSTEM DEVELOPEMENT

In the development of the control system, one adopts a methodology involving rules, logical operators and pertinence functions which map the input and output variables by adequate sensors, controlling each stage of the process. Figure 17 presents the proposed control system.

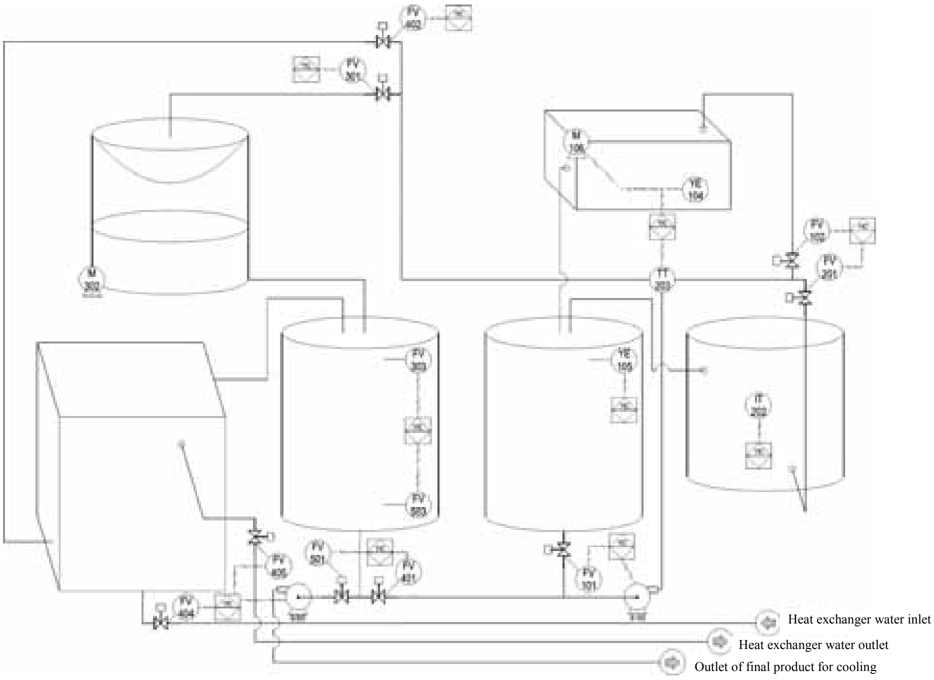

Figure 17. Symbology of the proposed manufacturing cycle of soya milk.

The actuation tendencies of the system are identified in real time with great precision, measuring the state of each equipment using the PLC. The temperature control, which is not the main focus of the work, is treated as handily operated contacts simulating that the temperature reached the desired value. In this case, the termocouple is the sensor, the boiler is the actuator, and the tank is the plant. The PLC sends the control signal to the boiler proportionally to the signal received from the termocouple, setting the temperature to the Set Point with help of a PID controller.

For heating the product, one adopted the temperature of 90^{o}C during 15 minutes, and for the pre-cooling one adopted the temperature of 30^{o}C during 5 minutes. The heating and cooling systems may have improvements regarding milk pasteurization and recycling of the water in the heat exchanger to avoid effort and cost waste. Figure 18 presents the division of stages in form of GRAFCET cycles. In cycle 0, all action elements (valves) are closed. When the proximity probes 100, 101 and 102 are in TRUE state (detection of product), the valves in cycle 1 are opened. When the proximity probe 101 is in FALSE state (product not present), cycle 2 occurs. As thermocouple 103 measures a temperature of 90°C, a timer is turned on (cycle 3), and after 15 minutes, cycle 4 occurs. When proximity probes 105 and 106 are TRUE, and 102 is FALSE, cycle 5 occurs. When thermocouple 103 reaches a temperature of 30°C, a timer is turned on (cycle 6), and after 5 minutes, cycle 7 occurs, thus finishing the process.

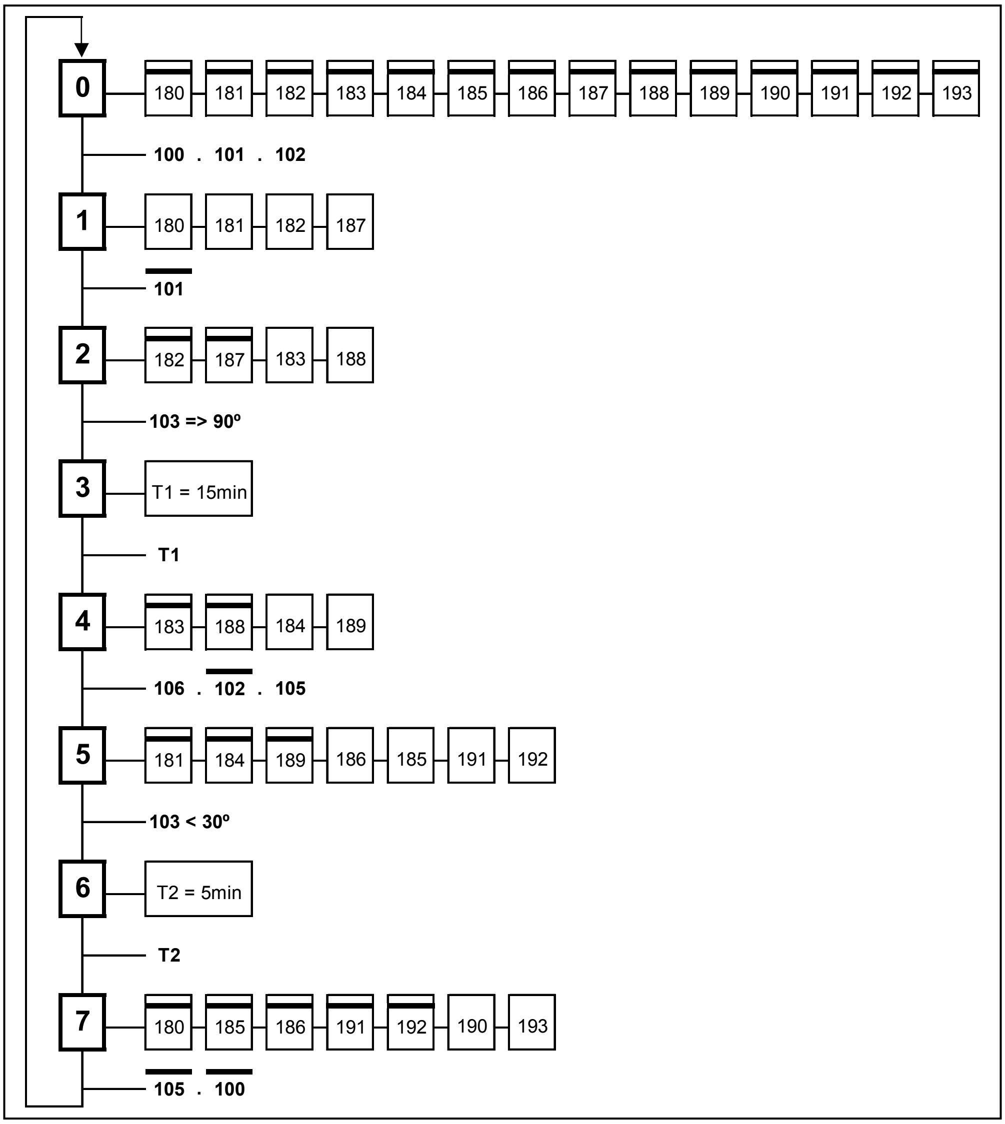

Figure 18. Diagram of the plant control (GRAFCET)

The supervisory software is the Elipse E3, DEMO version, which permits the manipulation and control of processes with a maximum of 20 TAGs. This software is dedicated to net operation and distributed applications, offering an advanced modeling of objects, a powerful graphic interface, and a new and exclusive architecture that allows fast development of applications and maximum connectivity to devices and hardware. Data acquisition is done in real time, using a LPC. The adopted interface is the serial port, although it is possible to use radio or modem (private or tone lines), TCP/IP or UDP/IP, board directly connected to the computer main board, and others. The E3 software reads and writes data from equipment through communication modules which implement the appropriated communication protocol (public or restricted protocols). The drivers can also be in a corporative format of Elipse Software or in OPC format (OLE for Process Control).

4. OBTAINED RESULTS

The obtained results are shown in each stage of the process. Each stage of the process was configured with the main tags due to the interface work in 2D. Figure 19 presents the product under milling and returning to tank 1 (green valve means open valve / red valve means closed valve).

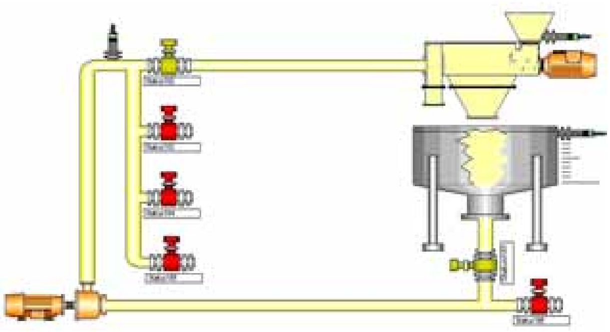

Figure 19. Visualization of stage 1.

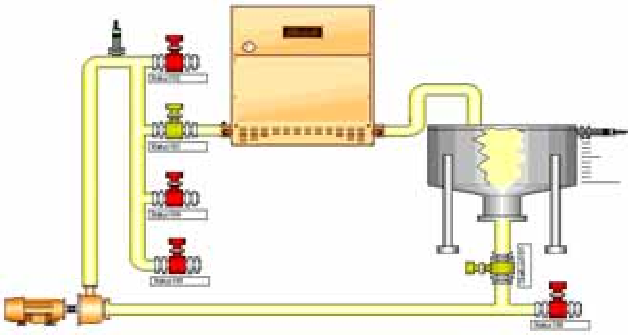

Figure 20. Visualization of stage 2.

Figure 20 presents the product being heated through the cycle in the boiler and tank1 (stage 2), where the product remains under pre-defined temperature and during pre-defined time. Figure 21 presents the centrifugation cycle for separating the protein mass and the soya juice, using tank 1, centrifuge, and tank 2 (stage 3). In the transition between stages 3 and 4 there is the addition of sugar and flavor to the soya milk (manual operation).

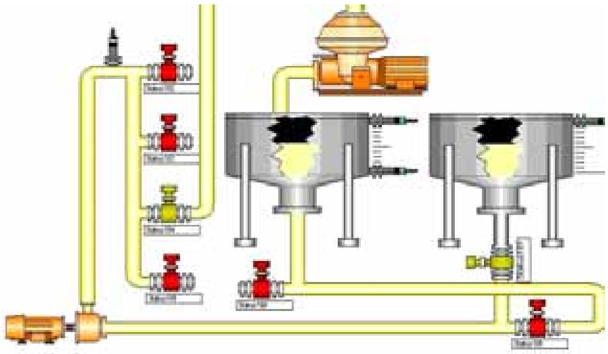

Figure 21.Visualization of stage 3.

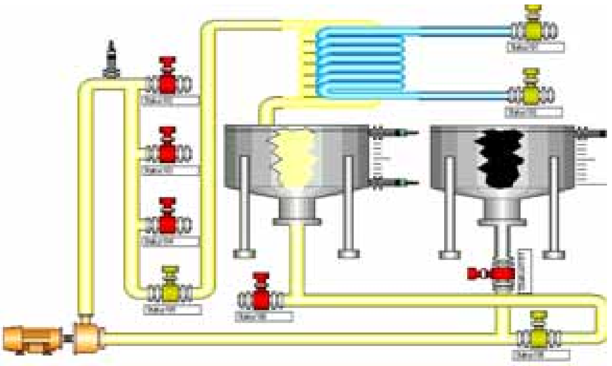

Figure 22. Visualization of stage 4.

Figure 22 presents the pre-cooling of the product for posterior freezing in tank 2 and heat exchanger (stage 4). Figure 23 presents the final cycle of the factory, where the product is sent to the freezer from tank 2 (stage 5).

5. CONCLUSION

By simulating the proposed automation process, there is evidence that it is possible to control the plant through a PLC and supervisory software for visualization of each stage of the process and monitoring in real time of process inputs and outputs. The adopted methodology and the simulation of the control process allowed the validation of data that have been used in practice.

The project is viable for implementation, and can include improvements in soya milk pasteurization and recycling of heat exchanger water. Therefore, the results guarantee the productivity expectations, cost saving, process lowering costs, plant flexibility and maintenance after installing the adequate equipment for monitoring and control.

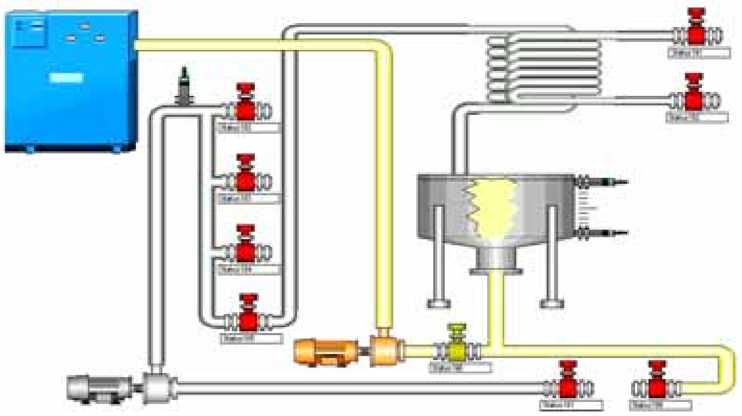

Figure 23 – Visualization of stage 5 in the supervisory software Elipse E3.

The multi discipline characteristics of the subject, involving mechanical engineering, control engineering, automation, biology, and food engineering, represents the difficulty encountered in the project development. The social benefits of such development must be highlighted, considering that it is expected an improvement of productivity in the public factory of soya milk in the city of Extrema (Brazil), whose control strategy was designed for.

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