Construction of a curd dosing machine for filling molds in cheese making for the microenterprise dairy "El Sr. Queso"

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Abstract. The development of this project of investigation is to shows the utility of cheese curds dosing machine in a small business that dedicated to make fresh cheese in the dairy industry. This machine will do a final product of quality, efficiency in the production, making easy the work of machine operator.

The main objective of the machine is fill the molds with adequate quantity of cheese curds avoiding waste, the cheese curds must be in an optimal status for the molding step, these are the mains troubles that is in the molding step of the cheese. So that the problem was resolved.

The approach of the solution began with the design of the mechanism parts chosen according to the needs of the small business. It was been dimensioned and choose the actuators and sensors of the each system.

It was been made necessary calculation for the building of each mechanic element of the machine and was been preceded to the total assemblage, implementing all attachments systems. To end was been made the necessary testing for the correct operation of the machine.

Keywords: dosing machine, curd, cheese, mechanisms.

1. Introduction

Using current technology have been optimized manual processes through the implementation of appropriate machinery to improve product quality in the dairy industry.

To market a higher quality product in this case the cheese, it is important to avoid physical contact of the worker with its ingredients. The process of filling molds with curd cheese production within the microenterprise is not adequate, since the operator must carry the curds from the pot to the molds manually which causes constant fatigue and careless operation of food. Additionally, considering the distance that must walk the worker adds an additional process, valuable production time.

Under these circumstances in the present work it is to design and implement a metering machine systems curd through current technology to ensure cheesemaking quality standards according to the needs that microenterprises. Through automating this process a final product of higher quality is obtained and the processing times of a cheese that will result in an increase in current production is reduced.

2. Content

A. Design, calculations and analysis of mechanical results.

The main parts of curd metering machine are:

- Plate metering orifices.
- Support structure.
- Caterer curd.
- Riel and adjustable plate.
- Tray molds.
- Tray gatherer.

To start the design of the machine is necessary to specify the material which will be built. All mechanical parts of the machine must be constructed with a stainless material due to Presidential Decree No. 3253 where the Good Manufacturing Practices (GMP) is detailed, so a steel AISI 304 is selected.

This steel AISI 304 to be of a composition of 18% chromium, 8% nickel and carbon <0.06% according to ISO 683 standard, react with the environment (oxygen) generating a protective layer that prevents the inner layers of steel corrode also this steel has a polished mirror type that provides easy cleaning (hygiene) and further increases its resistance to corrosion.

Plate metering orifices

The machine will be designed to fill 24 molds at a time by which the plate will have 24 holes distributed in two arrays of 4x3, the mold has a diameter of 101.6 [mm] that is 4 [inches], to ensure that the curd falls within the mold the diameter of the metering orifices is 90 [mm] ie have a diameter less than that of the molds. To this plate is added an extension of additional plate for the resting state of the curd.

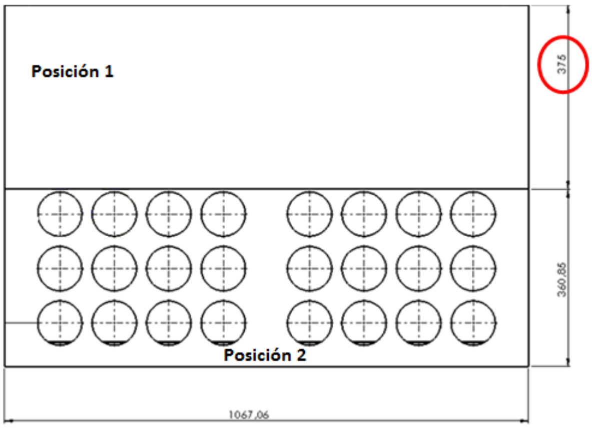

Figure. 1. Dimensioning plate metering orifices.

Support structure

The structure will be designed based on the dosing plate holes and all loads be submitted when starting operation. The height of the structure for reasons of comfort of the machine operator will be 900 [mm] meeting the design requirements. The length and width of the structure is defined by dispensing orifice plate and its extension.

Parameters	Length
Height	900 [mm]
Length	1067.06 [mm]
Width	735.85 [mm]

Table. 1. Parameters of the support structure

Caterer curd

The provider will have a rectangular shape to provide the curd to all metering orifices, the supplier will also be in charge of containing the curd in the draining stage. Their status or position defines its function within the machine, will eventually function scavenger to remove the excessive amount of curd if necessary.

For sizing the drawer it is considered that this must cover all metering orifices and containing a volume of curd needed to supply 48 holes, 48 molds, as may be done two cycles of dosing with the total capacity of curd provider.

Filling the mold volume per hole:

$$V_{mold} = A_{mold} * h_{mold}$$

Equation. 1. Mold volume

Where:

V_{mold} : Mold volume [cm3]

A_{mold} : Mold area [cm2]

h_{mold} : Mold height [cm]

So:

$$V_{mold} = \left(\pi * \frac{(10.16\ cm)^2}{4}\right) * 9.5\ cm$$

$$V_{mold} = 770.195\ [cm^3]$$

Below the minimum volume is calculated provider for dosing 48 molds:

$$V_{\min - \text{provider}} = V_{molde} * 48$$

Equation 2. Minimum volume Provider

Where:

$V_{min-provider}$: Minimum volume Provider

So:

$$V_{\min - provider} = 770.195\ cm^3 * 48$$

$$V_{\min - provider} = 36969.36\ [cm^3]$$

For the provider contains this minimum volume of curd are considered the following parameters listed below in Table 4.3:

Parameters	Length
Height	200 [mm]
Length	1015 [mm]
Width	328 [mm]

Table. 2. Design parameters provider curd

Then the total volume is calculated provider:

$$V_{total-provider} = h * l * a$$

Equation 3. Total volume provider

Where:

$V_{total-provider}$: Total volume provider curd [cm3]

h : Height provider [cm]

l : Length provider [cm]

a : Width provider [cm]

So:

$$V_{total-provider} = 20\ cm * 101{,}5\ cm * 32{,}8\ cm$$

$$V_{total-provider} = 66584\ [cm^3]$$

Taking into account the design parameters, the provider it will contain a maximum of 66584 [cm3] of curd and minimum capacity of the supplier to provide the 48 molds which together have a volume of 36969.36 [cm3], it is observed that the volume provider it is too exaggerated, but because the curd to be pumped to the provider is not a pure mixture (single pieces of cheese) for mixing with the whey is considered an additional calculation to justify this capability provider.

Since the mixture pumped to the provider contains 40% whey and 60% of cheese particles is considered a total volume of the mixture of 61615.6 [cm3], then the provider with a capacity of 66584 [cm3] would sufficient capacity to contain this volume and add 2 [cm] up to the provider because the mixture cannot be on the edge.

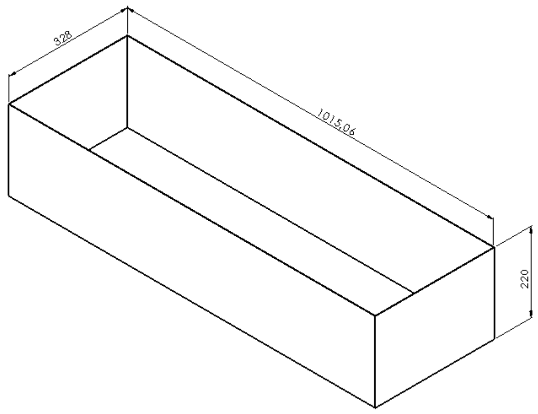

Figure. 2. Dimensioning provider of curd.

Because the highest percentage of draining no longer in the mold but in the provider, it is considered performing duplex perforations provider to improve draining stage within the provider. Drilling at the provider is 9.53 [mm] or 3/8 [inch] in diameter. Perforations are performed only on two sides provider (large faces).

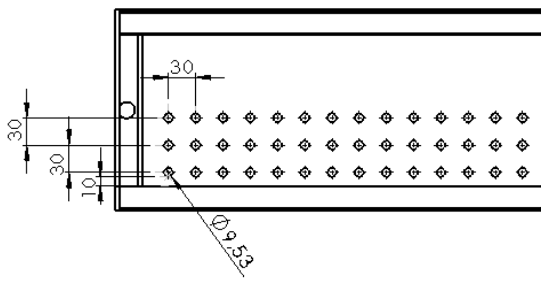

Figure. 3. Drilling provider curd.

Rail and adjustable plate.

The adjustable plate is in charge of regulating the attachment of the mold to avoid waste metering orifice at the stage of curd dosed.

To design the control system of attachment of the mold plate metering orifices a vertical channel installed to the support structure is performed, the adjustable plate slides through the vertical rail and is adjusted to a certain position by a mechanism threadable.

Because the machine has a distribution pattern molds for metered into two 4x3 matrices, the rails together with the adjustable plate will be designed to regulate the two arrays of molds at a time.

The rail adjustment depends solely on the height of the mold.

The threadable fitting will move through a vertical channel in the rail machining the adjustable plate.

This adjustable plate generates versatility filling machine mold different height.

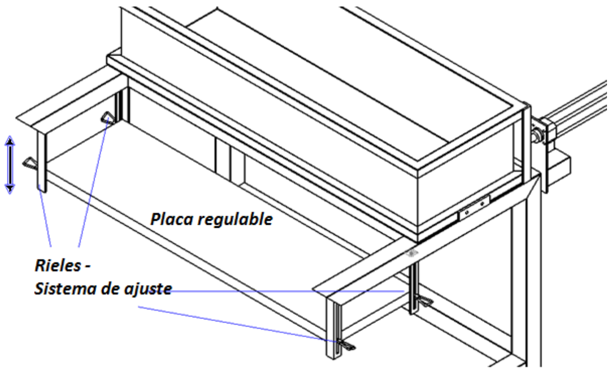

Figure. 4. Configuring the rail regulator.

Trays

The dimensions of the tray will be adjusted so that each mold is positioned concentrically with the holes dosed besides properly fitted and coupled with the machine thanks to the configuration of the support structure.

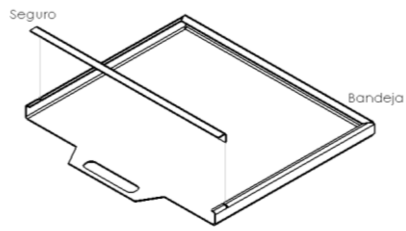

Figure. 5. Configuring the tray.

Drip tray

The drip tray is a container where all the excess whey and curd waste ejects the machine during its working cycle falls.

The dimensions of the tray are adjusted to prevent the whey and curd waste to be dumped out of the machine as these have a reuse.

The dimensions of the drip tray will be within the design parameters defined above.

Because of the way the machine the best option is to place the drain pan under the entire system performing the work to cover all the excess whey and curd. This tray will be installed at a height of 600 [mm] and setting floor is in the vertical members of the support structure.

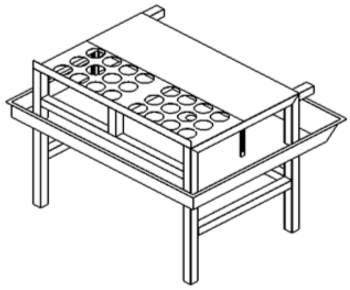

Figure. 6. Configuring the drip tray

B. Pumping System

The pumping system serves to feed curd provider, this system from the outlet of the pot to the provider connected via pipe stainless steel AISI 304 60.5 [mm] in diameter and a sanitary pump through.

Pump selection:

For selection of the pump is defined filling time provider to 1 minute, enough time to give an opportunity for the operator to complete a full cycle.

The selection of the pump takes place through a catalog of healthcare type pumps. The selection is the catalog of the brand INOXPA industrial pumps helical rotor model RV.

Using the techniques pumpcurves helical impeller industrial model RV shown in the catalog pump suitable for our system starting with the smaller capacity is selected, the requirements to be met are 2.15 [m] high pumping at a rate of 3.99 [m^3/h].

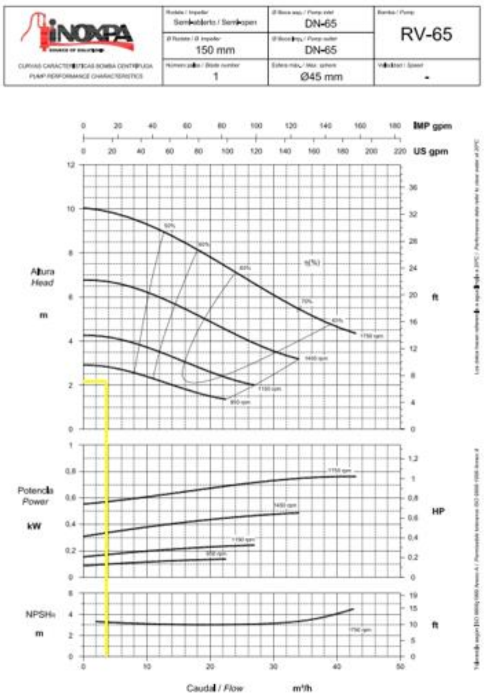

Figure. 7. Technical curve for pump selection

Pump RV-65 as indicated for our system to meet all requirements are determined.

C. Pneumatic system

The pneumatic system is responsible for generating the linear movement of the provider curd, the design has two pneumatic cylinders double effect two vertices coupled provider to avoid possible derailments on the guide rail.

Pneumatic actuators:

$$F_{cylinders} = Fr_{curd-plate} + Fr_{curd-plate}$$

Equation. 4. Calculating the frictional force curd-plate

Where:

$Fr_{provider-rail}$: Pneumatic cylinders Force [N]

$Fr_{provider-rail}$: Frictional force curd provider in the rail [N]

$Fr_{curd-plate}$: Frictional force curd and section 1 of the perforated plate [N]

So:

$$\boldsymbol{F_{cylinders}} = 262.66\ N + 78.03\ N$$

$$\boldsymbol{F_{cylinders}} = 340.69\ N = \mathbf{341\ N}$$

Since the design consists of two pneumatic cylinders 341 force [N] is divided by 2, i.e. two pneumatic cylinders with a minimum strength of 170.5 [N] necessary.

The technical characteristics of the selected pneumatic cylinders are:

Characteristics	Description
Type	Round cylinder, double acting
Carrera	350 [mm]
Stem diameter	12 [mm]
Minimum diameter of the plunger	32 [mm]
Theoretical retraction force to2.75 [bar]	190 [N]
Working pressure	1-9 [bar]

Table. 3. Technical characteristics of the selected pneumatic cylinders

For activation of a solenoid valve the pneumatic cylinders used.

Characteristics	Description
Valve type	**5/2**
Pressure Range	**1,5 – 8 [bar]**
Operating Voltage	**110 [VAC]**
Answer time	**0,05 [segundos]**
Connections	**1/8 [pul]**

Table. 4. Technical characteristics of the selected solenoid

A maintenance unit is implemented as a key element in the pneumatic system to provide uniform pressure, clean air and lubrication to prevent wear of the pneumatic actuators.

Characteristics	Descripción
Pressure Range	0,5 – 9 [bar]
Maximum pressure	10 [bar]
Particle removal	5 [micrones]
Work temperature	5 a 60 ºC

Table. 5. Technical characteristics of the maintenance unit

D. Control system

The control system of the machine has 2 stages: the first consisting of the filling control provider curd through the pumping system with an ON / OFF control depending on a certain status level as measured by a sensor the second stage is the tire driving mechanism that generates the dosed curd in the molds, this stage will be handled by the machine time to return to its initial state after dosing cycle.

As almost the entire process is automatic and control due to possible expansions of automation within the microenterprise is necessary to use a programmable logic controller is responsible for controlling all system variables so that the machine fulfills its purpose.

For the entire control system controller (PLC) is selected. Because the system needs a removable data management where the daily production of cheeses made by the machine, the PLC selected is Siemens LOGO! 0BA8 12/24 RCE, as this driver has this feature.

Characteristics	Description
Input voltage	100 a 240 [V AC]
Input current nominal value of the input voltage of 120 [VDC]	1,22 [A]
Permissible mains frequency	47 a 63 [Hz]
Protection device	Interna
Setting range	22,2 a 26,4 [V DC]
rated current	2,5 [A]

Table. 6. Technical features PLC

Sensors control system:

Sensor	Function
Limit switch	Check positioning provider curd
Level sensor	It measures the level curd provider for activation of the pumping system

Table. 7. Technical characteristics of the sensor control system

Flow chart of the operation of the control program:

In the following flow operation of the control system is as follows:

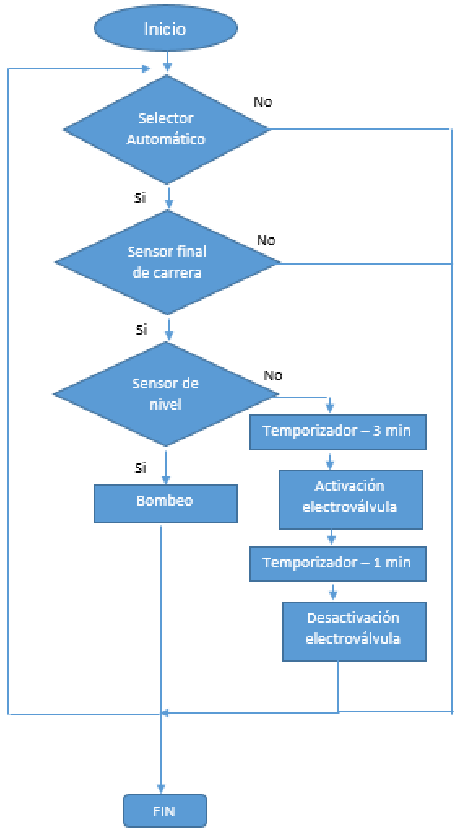

Figure. 8. Flow chart of the control program

3. Tests y results

A. Analysis and validation of the mechanical support structure

For a verification of the mechanical design of the supporting structure of the machine mechanical validation is performed by a software, corroborating the data by calculation.

A load of 500 [N] is considered about to be distributed to the two support beams, in the AB beams, with a load of 250 [N] applied to each, transforming it to a distributed load on the beam AB length 967.06 [mm] is 258.51 [N/m].

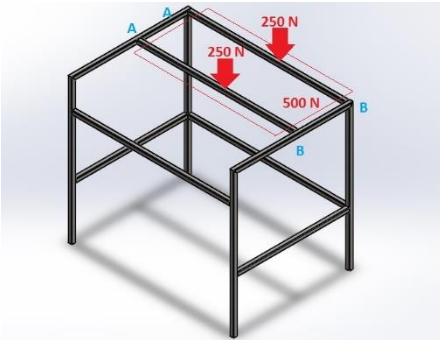

Figure. 9. Load distribution beams A-B

Moments and forces resulting from the beam A-B:

$$M_A = M_B = \frac{wl^2}{12}$$

Equation. 5. Calculation of the resulting time point A and B

Source: (Budynas & Nisbett, 2008)

Where:

$M_A = M_B$: Resulting moments [N.m]

w : Distributed load [N/m]

l : Length of beam [m]

So:

$$M_A = 20.14\ N.m\ ;$$

$$M_B = 20.14\ N.m\ ;$$

$$R_{By} = 125\ N\ ;$$

$$R_{Ay} = 125\ N$$

Efforts beam bending A-B:

Normal maximum bending stress, beam A-B:

$$\sigma_{max} = \frac{Mc}{I}$$

Equation. 6. Calculation of normal stress due to bending beam A-B

Source: (Mott, 2006)

Where:

σ_{max}: Maximum normal stress due to bending beam A-B [MPa]

M: Maximum bending moment of the beam A-B = 20.14 [N·m]

C: Distance from the neutral axis of the beam to the far fiber = 12.5 [mm]

l: Moment of inertia of square profile with respect to the neutral axis = 1.21 [cm4]

So:

$$\sigma_{max} = 20.8\ MPa$$

Maximum shear stress by bending beam A-B:

$$\tau_{max} = \frac{VQ}{It}$$

Equation. 7. Calculation of shear stress due to bending beam A-B

Source: (Mott, 2006)

Where:

τ_{max} : Maximum shear stress due to bending beam A-B [MPa]

V: Maximum shear beam A-B = 125 [N]

Q: First moment of inertia about the centroidal axis of the cross-sectional area of that part, which is on the opposite side of the shaft, next to where it will calculate the shear stress [mm3]

I: Moment of inertia of the cross section of the beam = 1.21 [cm4]

t: thickness profile where will calculate the shear = 1.5 [mm]

So:

$$\tau_{max} = 4.28\ MPa$$

Von Mises combined effort of beam A-B in 1:

In point 1 there is only normal maximum bending stress.

$$\sigma' = \sqrt{\sigma_x^2 + 3\tau_{xy}^2}$$

Equation. 8. Calculation of the combined effort of Von Mises point 1 beam A-B

Source: (Mott, 2006)

Where:

σ' Von Mises combined effort of point 1 beam A-B [MPa]

σ_x Normal stress in the x-axis beam A-B [MPa]

τ_{xy}: Shear stress in the x-axis, beam A-B [MPa]

So:

$$\sigma' = 20.8\ MPa$$

Beam safety factor A-B in 1:

$$N = \frac{Sy}{\sigma'}$$

Equation. 9. Calculation of safety factor point 1 beam A-B

Source: (Mott, 2006)

Where:

N Safety factor point 1 beam A-B

Sy: Yield strength [MPa]

σ' ': Von Mises combined effort of point 1 beam A-B [MPa]

So:

$$N = 10.57$$

Von Mises combined effort of beam A-B at point 2:

In point 2 exists only normal maximum bending stress.

$$\sigma' = \sqrt{\sigma_x^2 + 3\tau_{xy}^2}$$

Equation. 10. Calculation of the combined effort of Von Mises point 2 beam A-B

Source: (Mott, 2006)

Where:

σ' : Von Mises combined effort of point 2 beam A-B [MPa]

σ_x : Normal stress in the x-axis beam A-B [MPa]

τ_{xy} : Shear stress in the x-axis, beam A-B [MPa]

So:

$$\sigma' = 7.41\ MPa$$

Beam safety factor A-B at point 2:

$$N = \frac{Sy}{\sigma'}$$

Equation. 11. Calculation of safety factor point 2 beam A-B

Source: (Mott, 2006)

Where:

N : Safety factor point 2 beam A-B [MPa]

Sy : Creep resistance wing [MPa]

σ' : Von Mises combined effort of point 2 beam A-B [MPa]

So:

$$N = 29.68$$

All data obtained beam A-B is compared with the data provided by the simulation software to validate.

The following table shows the data obtained by calculation and the data delivered by the software, beam A-B comparison:

Data	Efford	Safety factor
Calculation	20.8 [MPa]	10.57
Software	18.97 [MPa]	10.90

Table. 8. Efforts and safety factors calculated and simulated beam A-B

The difference between the calculated data and software is tolerable, therefore valid simulation as acceptable then obtained from the simulation, the maximum axial tension and bending at the upper limit, the minimum safety factor and displacements resulting from any structure selected considering the structural profile that is a profile of 50x50 and 1.5 [mm] thick.

Data		Values
Axial tension and bending at the upper limit	**Maximum**	8.73 [MPa]
	Minimum	0.37 [MPa]
Minimum safety factor	**Maximum**	559.3
	Minimum	23.69
Resultant displacements	**Maximum**	1.62 x10-1 [mm]
	Minimum	1 x10-30 [mm]

Table. 9. Data structure simulation, square profile 50x50x1.5 mm

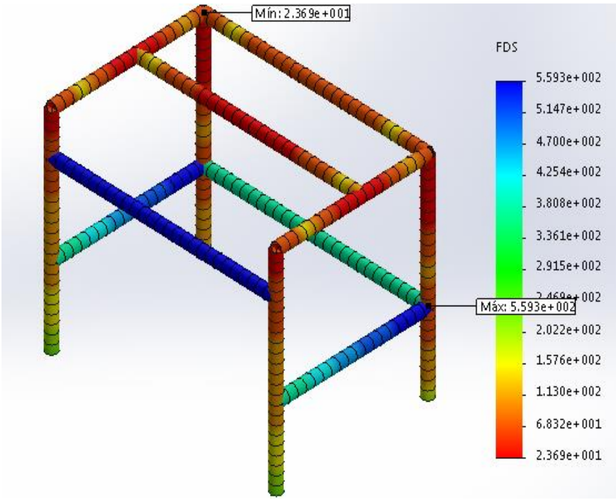

Figure. 10. Safety factor structure, square profile 50x50x1.5 mm

B. Analysis and mechanical validation of the perforated plate

Analysis software by the perforated plate to determine the safety factor is performed.

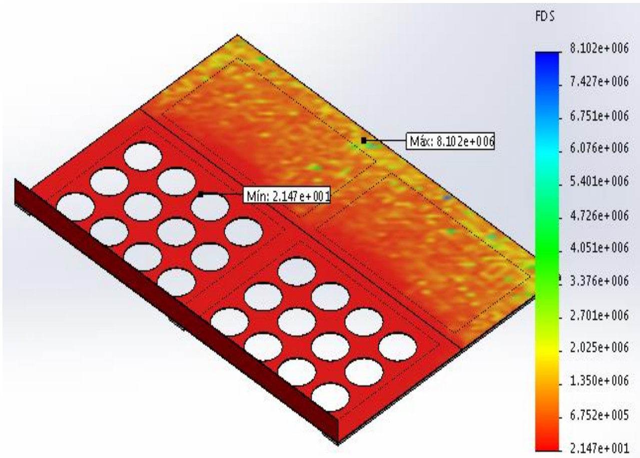

Figure. 11. Safety factor of the perforated plate

C. Performance testing machine

Initial tests with the intervention of curd

To ensure correct operation of the machine a next test is performed with curd intervention to ensure that there is no drawback in the whole process of operation, then a series of activities held in the testing of each system is as follows:

Mechanical system test

- Check that there is the least amount of losses curd by the supplier.
- Check the process of draining the curd provider.
- Check that there is minimum serum spills out of the machine.

Test pneumatics

- Check that the movement of the actuators move in alignment to the provider as working at full load can cause a misalignment in the rail provider.
- Check that the force actuators is suitable operating at full load.

Test pumping system

- Check pump suction and pumping rate.
- Review of the curd to check a possible mistreatment of selected rpm.

Test control system

- Level sensor behavior and behavior when working with curd.
- Review the electrical connections of the machine under a possible state of moisture.

Calibration systems

To have a cheese with features that the company requires the following tests were performed:

- Calibration filling height provider
- Calibration draining time.
- Calibration molding time.
- Calibration mold height.

After conducting several tests defined the exact level where you should fill up the provider.

For calibration draining time it is mainly considered the experience of workers checking how long it takes to reach the curd ideal for molding step point.

Mold height was calibrated after considering the exact state of the curd for molding. Mold height of 950 [mm] was considered.

He then considered several tests give a time of 90 seconds for the operator to verify each mold in the molding step.

4. Conclusions

- It was possible to reduce the time of filling the molds with the dosing machine curd, about 120 molds in a time span of 30 [min] before he made it 1 [time], then it is determined that the dosing machine curd reduces working time by 50%.

- It was possible to increase production by 3.33% because the dosing machine excessively curd reduces waste.

- The important parameters for the design of the machine were the available space, working height and holes dosed, and the main variables that were handled were the number of molds to dose, time draining, time manual verification, weight cheese, curd weight, volume and height supplier mold.

- Metering system was implemented by gravity, the system works by filling the provider of curd and after draining process is aimed at allowing simultaneous metering orifices of the molds admitted to the machine.

- A pneumatic system considering the needs of the machine directly to the linear movement focused provider of curd was implemented.

- A pumping system for transporting the curds from the pot to the provider by INOXPA RV-65 Industrial pump helical impeller, and a system level control was implemented through an infrared sensor SHARP GP2Y0A21YK to control filled provider.

- For optimal operation of the pump an angular velocity defined, whereby a speed reduction system was implemented through a mechanical speed reducer.

- Because the machine has a direct contact with the food, we chose rail placement in a place where the wear of the materials produced by the external friction and the curd is not suffer any contamination.

- In the process of operation he was the need for an audible alarm for the operator to be always aware of the actions of the machine avoiding any inconvenience by movement of the provider in step dosing.

- The maximum level measured by the sensor is configured for dosing of 24 molds, because the machine has better performance when working cycle dosed at once and not two as planned.

- Important variables defined in the testing process, these variables were: time draining as defined in 3 [min] which is very important to get a quality end product without alterations, and process time manual verification where the operator manually matched molds if they require it.

- Speed provider curd with generating the dosing was very fast, causing a stroke within the molds to dispense curd, dislocating the molds of the metering orifices in addition to excessive waste by violent income is generated curds into molds, because of this problem we chose removable adaptation safe in each tray and installation of air flow regulators in the pneumatic cylinders, thus regulating the speed of the provider.

5. Recommendations

- It is always recommended before starting the operating cycle of the machine check the air pressure of work.
- It is recommended to stop manipulating the molds filled or filled with curds that are inside the machine when the audible alarm is heard.

- Always be sized and build parts of a machine taking into account safety factors needed to avoid problems when the machine working at full load.

- Should implement a sweep away system annex to the provider, to avoid dosing uniform verification performed by the operator.

- The cleaning of each system and part of the machine must be provided before and after the operation due to handle a production process of food products.

- It is recommended that before any operation on the machine read and see everything contained in the manual and machine maintenance.

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