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CHEESECAKE WATER DOSING AUTOMATION

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ABSTRACT

The main objective of the Cheesecake Water Dosing Automation project was to design, construct, and implement a complete water dosing automation system for the Wegmans cheesecake production line, which allows a preset amount of water to be dispensed into sheet-pans that hold the cheesecake tins. A set of customer needs were acquired from Wegmans manufacturing group. The needs were matched with specifications to assist the generation of design concepts. A team of six engineers were then divided into groups to construct the mechanical components, electrical components, and to oversee the implementation of the final concept. The final product improves the water dosing process by removing the human element within the cheesecake production line, thus increasing the robustness and efficiency of the cheesecake baking process.

INTRODUCTION

Wegmans is a private, family-owned corporation that operates over 80 supermarkets, with their headquarters located in Rochester, NY.

The Bakery department of Wegmans manufacturing facility would like to improve the production efficiency of their manufacturing lines with the addition of new tools and automation. One part of this project is to enhance the water dosing process during the cheesecake making process.

During the cheesecake preparation stage, cheese cake batter is placed into cheesecake tins and the tins are then placed onto a metal sheet-pan. The cheesecake recipe requires water to be added to the sheet-pans before the baking process to keep the moisture of the cheesecake consistent. The current process involves one employee loading a row of 8 sheet-pans with ready to bake cheesecakes onto an oven loading area while another employee pours 2.5 quart of water into each of the sheet-pans before the oven loads the row of 8 sheet-pans.

However with the expected new expansion of the production line, the process is aimed to be automated to improve the cheesecake making process by providing a more ergonomic efficient solution and to increase the robustness and safety of the process.

The Cheesecake Water Dosing Automation project will create a system that automatically dispenses the correct amount of water into each sheet-pan on the oven conveyer belt. The process requires minimal human interaction and the device will require very minimal maintenance. The manual water dosing procedure will be replaced by an electronically controlled water device that uses a Programmable Logic Controller (PLC), sensors, solenoid valves, and a PLC built in electronic timers to coordinate the movement of sheet-pans and the water dosing process.

Control algorithms are employed in RSLogix software into the PLC to consistently and accurately control the conveyer belt's stops, solenoid valve functions, and the oven loading cycle, thus allowing the continuous correct movement of the manufacturing line by dispensing water at the right location.

The project also focuses on the design of a water extraction system for the post-bake process. Once the cheesecakes have gone through the baking process through the oven, the remaining water in the sheet-pans needs to be removed. An automated water extraction design was required to remove the water in an efficient manner.

PROCESS

NEEDS

The goal of this project is to provide Wegmans' Cheesecake Manufacturing Process an automated solution which will be implemented to the current process. The automated solution (Water Dosing Automation) will be capable to dose 2.5 quart of water to each metal sheet pan prior entering the oven. The Water Dosing Automation will improve the ergonomics of this process step without compromising total throughput. The implementation will not create issues to other processes operating on the same location at the different times of the production schedule. The dispense process have a period of time of 4 minutes and 40 seconds to fill the sheet pans with the required amount of water with minimal water splash.

SPECIFICATIONS

Wegmans needs were taken under consideration to generate engineering specifications. Each specification is aimed to define one or more need in a technical manner; with the primary goal to satisfy that need through quantitative measurements. Key engineering specifications were drawn up to identify and match the required needs. The design parameters listed in table (1) were established to meet the requirement of the automation process, at the request of Wegmans facility.

Metric	Units	Marginal Value	Ideal Value
Robustness of System	Downtime: min/week	<40	0
Minimal water Spillage	Cups	<0.1	0
Minimal variance of dispense amount	Cups variance	<1	0.5
System downtime	Percentage/ weekly	<4%	2%
Components are accessible	Inches	6 inches /part	12 inches/part
Minimum 21 quart of water deliverable from system	Quart	>21	24
Maximum 40 seconds to fill the 8^{th} pan	Seconds	<40	35
Minimal special training needed for repair	Hours of training	< 3 hours	1 hour
Removal of parts for cleaning will take minimal time	Minutes	< 15 minutes	10 minutes
Material is "food grade"	Material grade	"food grade"	"food grade"

Table (1) Engineering Metrics

CONCEPT GENERATION

To approach the problem of improving the current process of dosing sheet-pans with water for the cheesecake baking process, many concepts were generated and rated based on concept criteria. Concept criteria were rated based on the location of the unit, number of pans filled at once, and the method to which water is delivered. The Pugh Diagram, shown in table (2) was a tool used to identify and rate each concept generated according compatibility and plausibility of achieving the required specifications.

Criteria	Value	Datum	Concepts			
			1	2	3	4
Location of system	**7**		+	+	-	-
Input of water to system	**6**		**+**	**+**	**S**	**S**
Outlet of water to pans	8		+	S	S	-
Adequate timing to complete the job	5		S	S	-	-
Zero human interaction	8		+	+	+	-
Ergonomic setup is ideal for operators	5		+	S	-	S
System setup is user friendly	7		+	S	-	S
Within budget	8		S	S	S	S
Repairs costs are inexpensive	5		S	S	-	S
Minimal water spillage	8		S	S	-	S
Minimal repair time	6		S	S	-	S
System is safe for workers and other machinery	5		+	+	S	-
Easy to clean	5		S	S	S	S

Easily broken down to move and store	5		S	S	S	S
System can withstand physical abuse	7		S	S	S	S
System can withstand exposure to heat and water	5		S	S	S	S
	Total	+	7	4	1	0
	Total	-	0	0	5	6
	Total	Combined	7	4	-5	-6
	Weight	Total	46	26	0	0

Table (2) Concept Selection Pugh Diagram

Concepts generated are listed as follow:

1. Cat Eye Location – Place the water dosing unit near an already existing sensor that is on the cheesecake line currently.
   Hard-pipe to Flex-pipe – Water would be provided from a main water line then converted to flex-piping in order to hook up to the water dosing unit.
   Dispense 8 at a time – The water dosing unit would dispense and fill 8 sheet-pans at a time (8 sheet-pans in total).
   Variable time (2 Sensors) – The water dosing system will have the ability to adjust to different cheesecake loading times.
2. Between Conveyor and Cat Eye – Place the water dosing unit on a conveyor that is just before the cat eye location.
   Tank or tank/pump – The water dosing system would contain both a water tank and water pump in order to fill the cheesecake sheet-pans.
   Dispense 4 at a time - The water dosing unit would dispense and fill 4 sheet-pans at a time (8 sheet-pans in total).
   Variable time (2 Sensors) - The water dosing system will have the ability to adjust to different cheesecake loading times.
3. On Belt – Place the water dosing unit near an already existing conveyor that is located in the area after the cheesecakes were filled with cheesecake batter.
   Hard-pipe - Water would be provided from a main water line that would then be hooked up to the water dosing unit.
   Dispense 1 at a time - The water dosing unit would dispense and fill 1 sheet-pan at a time (8 sheet-pans in total).
   Fixed time (8 Sensors) - The water dosing system will not have the ability to adjust to different cheesecake loading times.
4. On Oven Bed – Place the water dosing unit around the already existing oven bed loading area that the cheesecakes get loaded onto currently.
   Hard-pipe to Flex-pipe - Water would be provided from a main water line then converted to flex-piping in order to hook up to the water dosing unit.
   Dispense 8 (with hose that can be flipped out of the way) - The water dosing unit would dispense and fill 8 sheet-pans at a time (8 sheet-pans in total).
   Fixed time (2 Sensors) - The water dosing system will not have the ability to adjust to different cheesecake loading times.

A datum rates the current application, however it is not applicable due to no current system in place. The rating system incorporates a series of pluses and minuses for a better or worse comparison than the current system respectively. If the concept generated the same performance as the current, then it is labeled with S for same rating.

By reviewing the result of the Pugh Diagram a decision was made to use concept 1, the Cat Eye Location concept. This concept allowed a system capable to meet required specifications. The concept involves using 2 sensors and flex-piping connection between the main water line and the water dosing unit.

CONCEPT OVERVIEW

Though further revision and review, only one solenoid valve was decided to be implemented due to the loading process of the sheet-pans on the conveyor belt. The conveyor belt stops when 8 sheet-pans are detected by the sensor, and then the valve opens to fill all 8 sheet-pans at the same time. The first concept was selected and also modified to satisfy the engineering specifications and the customer needs.

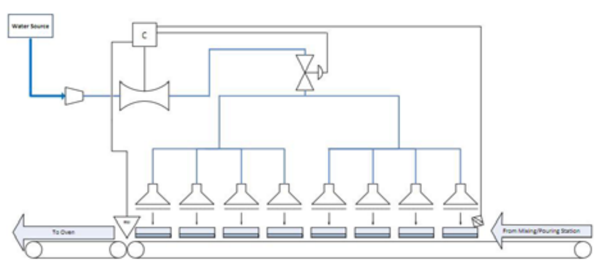


Figure (1) System Concept Overview

The team used a symmetrical branching design shown in Figure (1) for the water dispensing unit. The design allows the same water flow through each water outlet. Matching piping sections were cut and fitted for each separate branch. The connected unit is to be welded along the side of the conveyor belt on a long metal frame.

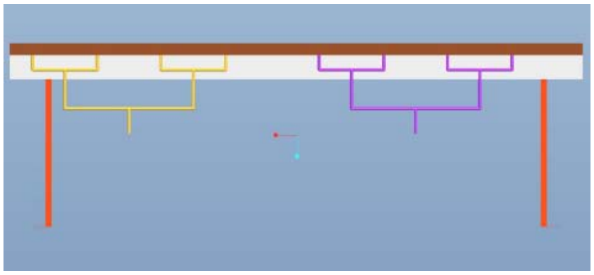


Figure (2) Conveyor Assembly

A water dispensing outlet is attached at the top of each piping branch and elevate over the conveyor belt. The water outlet is shown in Figure (2). The water outlet is designed to be detachable. The detached section of the pipe remains closed in case of a solenoid valve failure and water starts flowing in the pipe while outlet is detached.

The detachable water outlet serves two purposes. The major concern about the water dispensing unit is the collision of the water outlet with other baking good that the production line manufactures. The design of the outlet have to be close enough to the cheesecake sheet-pans to avoid splashing during water dosing, however other products may collide with the outlet if it is too low during times when cheesecake is not manufactured on the production line, thus where the detachable water outlet become useful. The second reason for a detachable outlet is for easy cleaning, storage and maintenance.

A water flow regulator is placed before each dispense nozzle to change the water flow into the nozzle. The flow regulator allows adjustment in each nozzle for even water dispensing in all eight sheet-pans. The nozzle design is shown in figure (3).

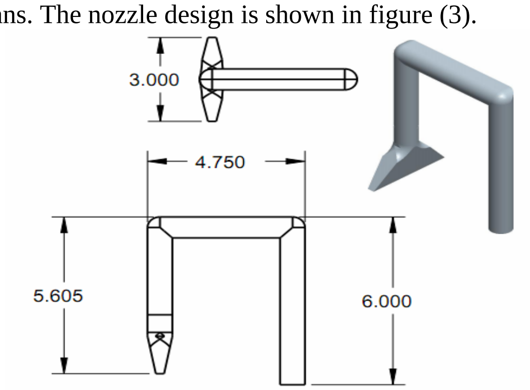
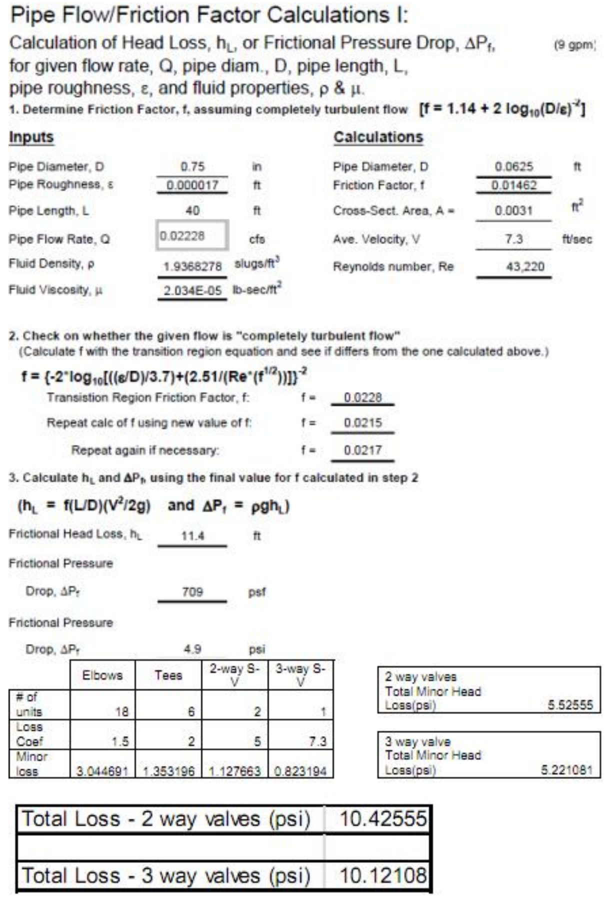


Figure (3) Elevated Water Outlet (Inches)

ANALYSIS AND EVALUATION



Pipe Flow/Friction Factor Calculations I:

Calculation of Head Loss, h_L, or Frictional Pressure Drop, ΔP_f, (9 gpm)
for given flow rate, Q, pipe diam., D, pipe length, L,
pipe roughness, ε, and fluid properties, ρ & μ.

1. Determine Friction Factor, f, assuming completely turbulent flow $[f = 1.14 + 2\log_{10}(D/\varepsilon)^{-2}]$

Inputs			Calculations		
Pipe Diameter, D	0.75	in	Pipe Diameter, D	0.0625	ft
Pipe Roughness, ε	0.000017	ft	Friction Factor, f	0.01462	
Pipe Length, L	40	ft	Cross-Sect. Area, A =	0.0031	ft^2
Pipe Flow Rate, Q	0.02228	cfs	Ave. Velocity, V	7.3	ft/sec
Fluid Density, ρ	1.9368278	$slugs/ft^3$	Reynolds number, Re	43,220	
Fluid Viscosity, μ	2.034E-05	$lb\text{-}sec/ft^2$			

2. Check on whether the given flow is "completely turbulent flow"
(Calculate f with the transition region equation and see if differs from the one calculated above.)

$f = \{-2*\log_{10}[((\varepsilon/D)/3.7)+(2.51/(Re*(f^{1/2})))]\}^{-2}$

Transistion Region Friction Factor, f: f = 0.0228
Repeat calc of f using new value of f: f = 0.0215
Repeat again if necessary: f = 0.0217

3. Calculate h_L and ΔP_f, using the final value for f calculated in step 2

$(h_L = f(L/D)(V^2/2g)$ and $\Delta P_f = \rho g h_L)$

Frictional Head Loss, h_L: 11.4 ft
Frictional Pressure Drop, ΔP_f: 709 psf
Frictional Pressure Drop, ΔP_f: 4.9 psi

	Elbows	Tees	2-way S-V	3-way S-V
# of units	18	6	2	1
Loss Coef	1.5	2	5	7.3
Minor loss	3.044691	1.353196	1.127663	0.823194

2 way valves Total Minor Head Loss(psi) 5.52555

3 way valve Total Minor Head Loss(psi) 5.221081

Total Loss - 2 way valves (psi)	10.42555
Total Loss - 3 way valves (psi)	10.12108

Figure (4) Head Loss Feasibility Analysis

To ensure the water dispensing unit would be able to meet the system's needs, the selected concept was put through a feasibility analysis. The functionality of the water output, pressure and flow rate of water the system could access were analyzed through several head loss calculations. The calculations prove that the system is able to supply the required volume of water at an acceptable pressure to fulfill Wegmans demands. The detailed calculation is shown in figure (4). The calculations also show that the system can operate appropriately without additional water storing tank or water pump support.

A feasibility analysis was conducted to verify the automation process's ability to maintain the current manufacturing throughput. The automation process must dispense and load all 8 sheet-pans oven cycles once every 4 minutes and 40 seconds. Following is a comparison of the current process timing and concept process timing. The result in figure (5) shows the time to fill a set of 4 sheet-pans is 22 seconds. Since the concept is modified to fill 8 sheet-pans at once in less than 16 seconds, the analysis shows that the concept is acceptable and will maintain the proper throughput.

Throughput Analysis – Time Comparison

A_1 = First set of 4 pans A_2 = Second set of 4 pans
B_1 = Third set of 4 pans B_2 = Fourth set of 4 pans
C_1 = …

Current Process Time Study

Time Slot	Conveyor	At Stop	Oven	Dose Water	Oven Cycle
4:40/ 0:05	A_1				cycles
2:00	A_2	A_1			
4:00		A_1 & A_2			
4:40/ 0:05	B_1		A_1 & A_2		cycles
1:40				A_1	
2:00	B_2	B_1			
3:20				A_2	
4:00		B_1 & B_2			
4:40/ 0:05			B_1 & B_2		A_1 & A_2

Proposed Process Time Study

Time Slot	Conveyor	At Stop/ Dose	Dose Done	Oven	Oven Cycle
4:40/ 0:05	A_1				cycles
2:00	A_2	A_1			
2:22	A_2		A_1		
4:00					
4:22		A_2	A_1 & A_2		
4:40/ 0:05	B_1			A_1 & A_2	cycles
2:00	B_2	B_1			
2:22	B_2		B_1		
4:00		B_2			
4:22			B_1 & B_2		
4:40/ 0:05				B_1 & B_2	A_1 & A_2

Time to fill a set of 4 pans = 22 seconds

Figure (5) Throughput Feasibility Analysis

TESTING

The speed of the conveyor belt was tested to obtain the optimal speed for reducing water splash from the initial acceleration of the belt after water is dosed. The result indicated a new conveyor belt driver needs to be installed. The current conveyor belt runs on a maximum 15 seconds timer to transport the filled sheet-pans from under the unit to the oven. The velocity and acceleration is too fast using a 15 seconds time frame. The new timer installed allows the belt to travel much slower and longer, thus reducing water splash over the manufacturing line.

The timing for a manual valve triggered dispensing is recorded and programmed into the PLC after the speed of the conveyor belt is optimized. The time it takes to fill the pans is recorded and entered into the PLC for electrical control. Once a rough estimate time for solenoid valve open time is established, a more fine timing can then be calibrated. The flow of water during the dispense process will be measured and matched against the specification of ideal flow rate and the feasibility analysis. Additional testing will be conducted to verify splashing is kept to a minimum or none. The design of the system with the overhanging nozzle seen in figure (7) reduces the initial splash. If splashing occurs during the dispensing process, then the pressure regulator can be adjusted to lower the water pressure to reduce flow.

After the main water line is attached to the device, the flow at each individual dispense nozzle was measured by opening the main water line and allowing water to flow through the device. Two gallon size buckets were placed under each nozzle to catch the flowing water. The water depth in each bucket was measured at 2.5 quart. The flow regulator shown in figure (6) was adjusted according to the amount of variation of water depth in each bucket.

Figure (6) Flow regulators installed at each dispense head to change the flow of water in each sheet-pan.

RESULTS AND DISCUSSION

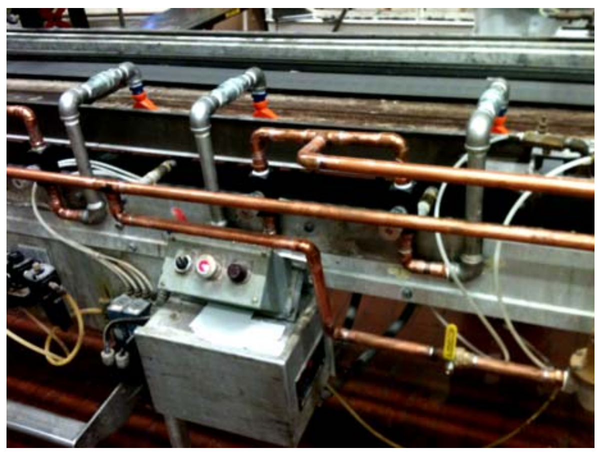


Figure (7) General overview of the system with piping and dispense heads.

The speed of the conveyor belt was optimized to allow slow movement of the sheet pans and yet fast enough to clear the last dosed pan from the pan stopper before the next set of 8 pans gets stopped to be filled. The most optimal hertz tested for the conveyor belt ranges between 30-35 Hz (Markings have been made on the speed dial to indicate the value as seen in figure (8)) The final testing shows that the behavior of the pans with the filled cheesecake tins on top moves more uniform and lines up tighter before the oven than empty sheet-pans.

Figure (8) Speed adjustment control with lower marking at 30 Hz and higher at 35Hz

The device showed a performance that met the requirement in the specifications. The desired water amount was achieved in a dispense time of 20 seconds across all eight sheet-pans. There was very little variation of water amount due to the adjustments made in the flow regulators. The highest variation was measured to be +0.14 quart.

The communication between the cat-eye sensor and the conveyor belt is programmed into the PLC. When the eight sheet-pans arrive at the sensor, the pan catcher flips up and stops the eight pans from moving to the oven. Then the PLC triggers the solenoid valve to correctly open the main waterline. The water dispense occurs for the set time duration and then the pans are released into the oven once the oven cycle of 4 minutes 40 seconds triggers.

The 9th pan is stopped by the pan catcher shown in figure (10) and then caught by the pan stoppers shown in figure (9) in order for the next set of eight pans to properly be dosed. The pan catcher is set on a pulse of 105 to properly catch the 9th pan by a pulse counter shown in figure (11) located below he conveyor belt. The pan stopper props up when there is no pan detected by the sensor. The sensor for the pan stopper is shown in Figure (9) as the round object in between the belts. The proper communication between the PLC, sensor, and the solenoid valve is established. The network is controlled through the PLC logics.

Figure (9) Pan Stopper rises from the conveyor belt to stop pans from moving further.

Figure (10) Pan Catcher stops the 9th pan after the pulse counts to 105.

During the last set of pans, if there is not enough pans to make a set of 8 sheet-pans, then the sensor will not trip and water dispense will not begin. To avoid this, additional empty sheet-pans are needed to be placed on to the conveyor belt to complete the last set of 8 sheet-pans. Water will be dispensed into the sheet-pans without the cheesecake.

Figure (11) Pulse counter in place for the conveyor belt set to 105 pulses for the pan catcher to trigger.

In case of an emergency, a failsafe manual shutoff valve can be closed to make sure no water flows through the device, which to ensure the device is able to be controlled other than through the PLC to prevent unforeseen accidents.

CONCLUSIONS

The Cheesecake Water Automation Project performed by the students of the Rochester Institute of Technology at Wegmans facilities concludes a successful Multi-disciplinary Senior Design project. After several testing procedures and several system changes, the team of engineers along with the Wegmans' mechanic, Chris Osborne, was able to analyze the system implementation working properly in a real scenario setting.

Based on the test results, utilizing the water dose device constitutes the adequate 2.5 quarts of water that a sheet pan requires prior entering the oven. The final tests also sustain that the implementation is a fully automated device capable of pouring water to eight sheet pans at the time. The device has also the capabilities to communicate with the main PLC and the oven's control box to identify when it is required to operate.

Even though the implementation was categorized as positive by Wegmans managers and supervisors, there are a few adjustments that will need to take place in the future as the system adapts to the manufacturing environment and the process redesign. It can be finally concluded that the Senior Design team was able to develop a functional solution that addresses the previous ergonomic faults of the process and meet the customer requirements of a fully automated device.

FUTURE WORK

The scope of the senior design project included both the inlet portion of the line where water was supplied to the pans through an automated system but also include the offload portion of the line where workers were required to dump out the excess water that was still in the pans after the baking process. Because of the extensive nature of both sides of the project the outlet was removed from the project under the condition designs were to be proposed at the end of the project. Three different designs were created and presented to Wegmans on the hope that they could spark ideas for a follow up senior design project or even a follow up project attempted by Wegmans themselves. Figure (12) shows proposal 1.

The proposals sparked a quick test session where the team would use a shopvac to attempt to remove water from a pan in order to validate the designs. The hope for the future is that either through cooperation with the Rochester Institute of Technology and a senior design team or just a self-sponsored project attempted by Wegmans that all human interaction on the line in positions where injury could occur or worker safety is compromised will be removed and the system will be fully automated.

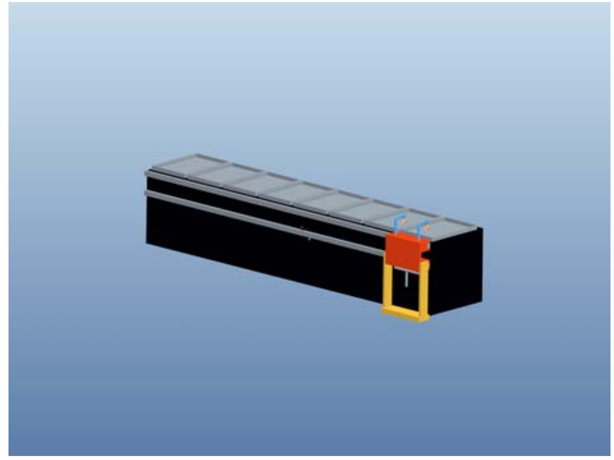


Figure (12) Outlet proposal using shopvac

ACKNOWLEDGMENTS

The team would like to express our gratitude to all those who assisted towards the success of the project. In particular we would like to extend our thanks to Mike Least from the Wegmans, for his time and commitment to the team and overseeing the success of the project; Chris Osbourne for major assistance in the physical implementation of the system and contribution in testing; Professor John Kaemmerlen from Rochester Institute of Technology, for providing essential insight and advice towards the project success.