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Co-Editors-in-Chief

Changfeng Ge
Packaging Science
Rochester Institute of Technology
One Memorial Drive
Rochester, NY 14623-5603
Phone: 585-475-5391
Email: cfgmet@rit.edu

Bruce Welt
Packaging Science
University of Florida, Box 110570
Gainesville, FL 32611-0570
Phone: 352-392-1864, X-111
Email: bwelt@ufl.edu

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Transfer Machine Line for Packaging Granular Materials in a Soft Open Container

A. M. MAKAROV[1,*], Y. P. SERDOBINTSEV[2] and M. P. KUKHTIK[3]

[1]Senior Lecturer, Volgograd State Technical University, Volgograd, Russia
[2]Professor, Volgograd State Technical University, Volgograd, Russia
[3]Postgraduate, Volgograd State Technical University, Volgograd, Russia

ABSTRACT: There has been described a brief analytical overview of the market of granular materials, devices and ways of packaging thereof in Russia. A family of lever-hinged capturing devices has been developed for automation of the filling process of folded containers such as open sacks. Some researches and calculations confirming the working capacity of these systems have been made. A scheme and 3-dimensional computerized model of a transfer machine line for packaging granular materials in folded containers has been suggested.

1.0 INTRODUCTION

GRANULAR MATERIALS have been widely adopted in food (sugar, flour, dry milk, cereals, nuts, legumes, etc.), chemical (mineral and organic fertilizers, pesticides, ice-melting products, powders, granulated blends, etc.) industries, in construction (sand, rubble, cement, bloating clay, hydration (bonding) substances, etc.), agriculture (grains, oil cultures, animal fodders, etc.), and also in daily life of man. At present, granular material dosing, packaging, and transportation processes take one of the leading places. Yearly, all kinds of transport carry more than 5 billion tons of finished granular loads in Russia. More than a half of them are carried in closed means of transport or special shipping containers (sacks, drums, containers, etc.). The share of folded container loads (sacks, "big baggies", and plastic package) is 40 per cent of all container-carried granular materials.

*Author to whom correspondence should be addressed. E-mail: amm34@mail.ru

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An important stage in the transportation-technological schemes of supplying granular materials from the producer to the final consumer is a process of bagging and packaging thereof in different container types. By preparing the bagging production, it is necessary to remember that granular materials are often heavily dust-producing, sometimes explosive or toxic. Presence of such products at bagging operations is dangerous for health, labour-intensive, tiring, and accidental for man. Therefore, they try to completely or partially automate these operations. The solution for the problem of automatic bagging for open sacks of different materials (e.g., jute fabric, polypropylene) is made difficult by complexity of capturing and manipulating containers, whose material conducts air, as well as necessity to stitch a sack gusset right after filling. Therefore, the bagging process into such containers goes with hand labour application.

2. THEORETICAL INVESTIGATION

The authors suggest using lever-hinged capturing devices (LHCD) to solve the problem of automatic opening and holding sacks. A family of such devices [1–3] has been developed, which contain capturing elements in the form of fingers and a drive for moving thereof in the form of one or several pneumatic cylinders.

To automatically capture a sack, which is in a pile, it is necessary to perform preliminary opening thereof, e.g., using vacuum and pneumatic swirling claws by hefting the gusset of the top sack. Whereby, the lower part of its gusset swags and opens the internal chamber. The equation of a sack gusset swagging curve is calculated by variational calculation methods in the form of a swagging problem solution for a thread freely appended from two sides [3], and it is given by:

$$y = C_1 \cdot ch\frac{x - C_2}{C_1} - \lambda \tag{1}$$

where $ch(z)$ is a hyperbolic cosine of the function, C_1 and C_2 are arbitrary constants of integration, and λ is an indefinite multiplier, which values are determined from the initial and boundary conditions.

Thus, for a case when the sack is slightly opened and held by two vacuum claws located at one height, the system of the equations for determination of values of C_1, C_2 and λ is given by:

$$\begin{cases} C_1 \cdot ch\dfrac{-C_2}{C_1} - \lambda = 0 & (\text{at } x = 0 \to y = 0) \\ C_1 \cdot ch\dfrac{a - C_2}{C_1} - \lambda = 0 & (\text{at } x = a \to y = 0) \\ C_1 \cdot \left(sh\dfrac{a - C_2}{C_1} - sh\dfrac{-C_2}{C_1} \right) = 2B - a & \begin{pmatrix} \text{the length of the sagged} \\ \text{part equals } 2B - a \end{pmatrix} \end{cases} \quad (2)$$

where $sh(z)$ is hyperbolic sine of the function, B is width of the sack, a is distance between external edges of vacuum claws.

By solving the system of the Equations (2) it is possible to define values of λ, C_1 and C_2. Thus, if you take a standard size sack according to GOST [4]: the sack length L is 104(±1) cm, the sack width B is 56(±1) cm, we obtain: $\lambda = 43.3$; $C_1 = 31.7$; $C_2 = 26.4$.

Then, the equation of a swagging curve for the lower part of a sack gusset is given by:

$$y = 31.7 \cdot ch\frac{x - 26.4}{31.7} - 43.3 \text{ (cm)}$$

A slightly open sack gusset allows the LHCD fingers enter inside. Then, capturing and transportation of a sack to the loading spout is performed with the help of expansion of the device outermost side fingers. Being under the loading spout, the sack opens, the base thereof being on the conveyor belt and the gusset held by means of arching forces T, which act from LHCD fingers. These efforts T must not exceed the maximum permissible (breaking) force of the sack fabric T_{max} (defined from reference data or GOSTs for sacks and fabrics for sacks of different fabric types). In the meantime, they must be sufficient for holding a sack by bagging, i.e. exceed T_{min}—the minimum essential effort for holding a sack, which is defined by formula [5]:

$$T_{\min} = \frac{0.86 K \rho B^4}{2L - B} \quad (3)$$

where ρ is packed density of the material, L is length of the sack correspondingly, and K is the factor of safety, $K = 1.3 – 1.5$.

Thus, for the above mentioned standard polypropylene sack under GOST [4], breaking force T_{max} is 294 N. Packed density for sugar ρ depends on humidity and dispersion structure thereof, and it is defined by GOST [6]. To calculate, let's take maximum allowed packed density for sugar ρ equal to 900 kg/m³. By inserting all the values chosen into formula (3), we find the minimum essential efforts for holding the sack:

$$T_{\min} = \frac{0.86 \cdot 1.4 \cdot 900 \cdot 0.56^4}{2 \cdot 1.04 - 0.56} = 70 \text{ N}$$

Then the efforts needed to hold the necessary polypropylene sack by bagging it with sugar shall be chosen within 70 N to 294 N. These efforts in LHCD constructions must be created by compression springs [1] or through air pressure in the head ends of the power mini-cylinders [2].

3. COMPUTER MODELING

The researches and calculations done have allowed to suggest a transfer machine line scheme for packaging granular materials into sacks [Patent 2469928 RF, MPK B 65 B 7/02 (2006.01). A Device for Automatic Opening, Holding and Closing of Sacks/ A. M. Makarov, L. A. Rabinovich, Y. P. Serdobintsev—No. 2011122137; applied on 31.05.2011; issued on 20.12.2012; VSTU].

Via student version of 3D computer graphics software for making 3D animations, models and images Autodesk 3ds Max 2012, a 3-dimensional computer transfer machine line model has been obtained (Figure 1), which contains capturing mechanism, 1, with fingers mounted on

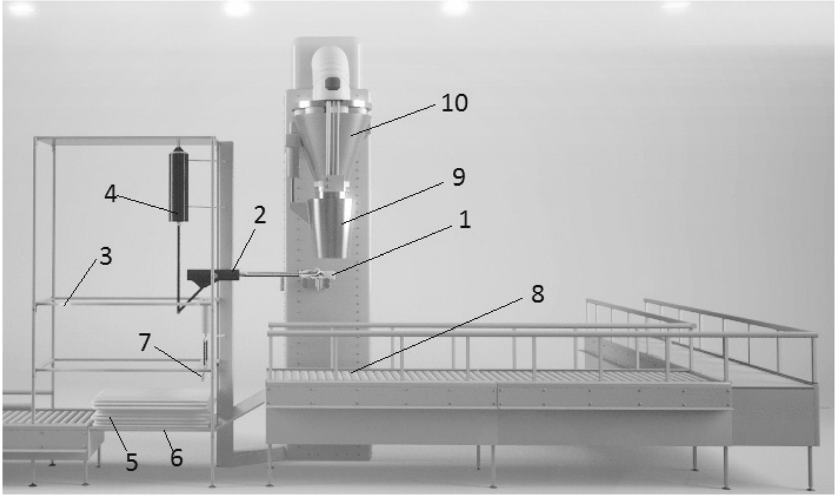

Figure 1. *3-dimensional computer transfer machine line model for packaging granular materials.*

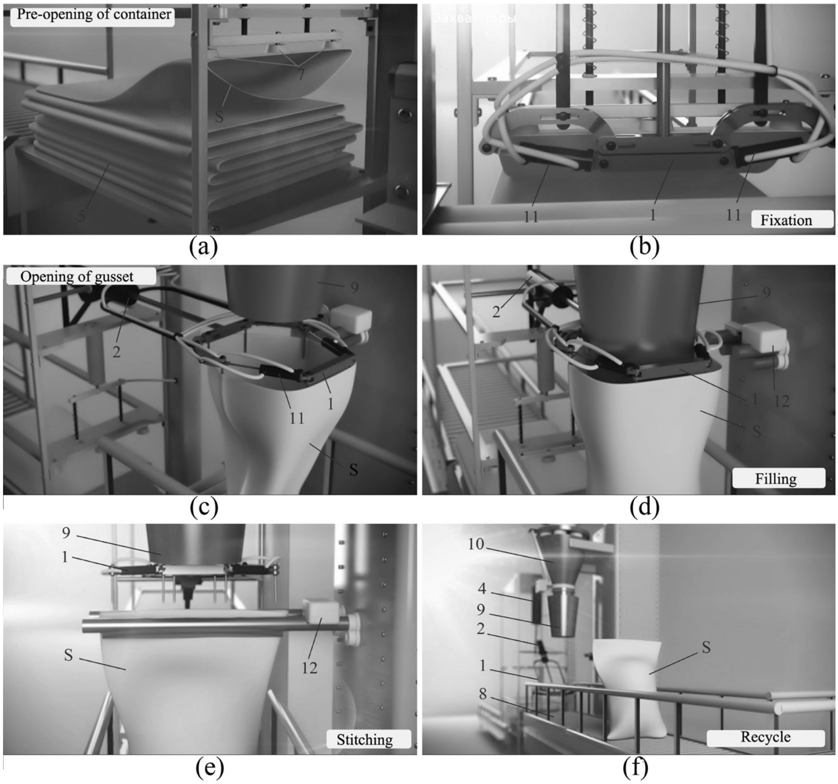

Figure 2. *Computer modeling of the granular material packaging process into folded containers such as sacks.*

the pneumatic cylinder of drive, 2, hinged-mounted on frame, 3, with a possibility to turn via pneumatic cylinder, 4.

Sack pile, 5, is on lifting table, 6. Vacuum claws, 7, are connected with tubes to the air-system and mounted with possibility of vertical axial movement. Conveyor belt, 8, is located under loading spout, 9, connected with batcher, 10. Loading spout, 9, is made with a possibility of linear vertical movement.

An automatic sack bagging process with granular material has been modeled on the basis of a 3-dimensional computer transfer machine line model. Some fragments of a video received in the course of the line operation process modeling are represented in Figure 2.

In its initial condition, sack pile, 5, is laid horizontally on lifting table, 6, vacuum claws, 7, are over the unstitched sack gussets, capturing mechanism, 1, and pneumatic cylinder, 2, are located horizontally, and loading spout, 9, is up.

At the beginning of a regular cycle, vacuum claws, 7, are pressed to the surface of the gusset of sack, S, which is on the pile top. Moving vacuum claws, 7, to their initial position results in separation of upper sack, S, from the pile, whereby the lower part of the gusset thereof swags under the effect of its own weight while opening the internal chamber of the sack [Figure 2(a)]. Pneumatic cylinder, 2, with capturing mechanism 1 turns and the LHCD fingers enter inside sack S gusset. The extension of pneumatic cylinder, 11, rods draws the outermost side hinges with capturing mechanism, 1, fingers. Simultaneously, vacuum claws, 7, are disconnected from the vacuum system, thereby sack, S, is captured and held on the LHCD fingers [Figure 2(b)]. Holding sack, S, is performed by means of frictional interaction forces of the finger surface of capturing mechanism, 1, with the sides of sack, S, gusset, as well as by means of damping properties of air in the head ends of pneumatic cylinders, 11.

Then capturing mechanism, 1, returns to its initial position and by way of retracting the rod of pneumatic cylinder, 2, opens sack, S, gusset by locating its hinges with fingers along the perimeter of the open sack gusset what ensures holding thereof [Figure 2(c)]. Whereby, sack S base is on the conveyor belt, 8, directly under the LHCD fingers and loading spout, 9, which goes inside sack, S, gusset down to the level of capturing mechanism, 1. Filling of a product portion previously weighed by batcher, 10, starts [Figure 2(d)]. Upon completion, loading spout, 9, goes up to its initial upper position, capturing mechanism, 1, closes the sack gusset by retracting the rod of pneumatic cylinder, 2, and preparing the sack for stitching with special stitching machine, 12, which is nominally shown in Figure 2(e). Whereby, sack, S, is freed from capturing mechanism, 1, fingers, and being on conveyor belt, 8, it is transferred to the shipping point or storage location [Figure 2(f)]. Here, the sack filling cycle finishes.

CONCLUSIONS

The automatic transfer line suggested can be used in different industries for packaging granular materials in open folded containers of different types and sizes. Whereby, LHCD [2] construction allows to capture and open sacks of not only one standard size, but also ones of close dimensions, i.e. perform filling of different size containers without additional equipment readjustment.

Using the automatic transfer line suggested allows to completely free the man-power from heavy, tiring work, take them out of the operating area and not to apply manual labor in processes of filling granular products in folded containers such as sacks of different materials any more.

ACKNOWLEDGEMENT

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Effect of Glue Pattern and Volume at the Manufacturer's Edge on Strength of Corrugated Fiberboard Containers

J. SINGH[1], S. SMITH[1], K. SAHA[1,*] and S. ROY[2]

[1]*Packaging Program, Orfalea College of Business, Cal Poly State University, San Luis Obispo, CA, USA*

[2]*Statistics Department, Cal Poly State University, San Luis Obispo, CA, USA*

ABSTRACT: A box blank is a flat piece of corrugated fiberboard, which has been cut, slotted and scored. To convert it into a box, its two ends must be fastened together with tape, staples or adhesives such as water soluble glues. The location at which the two ends meet is known as the manufacturer's joint. While taped and stapled joints are used for specific applications, glued joints have been reported to be the most preferred. This paper reports the observations for the effect of glue patterns and their respective volumes on the strength of corrugated fiberboard boxes as related to both the vertical and horizontal stresses. By testing tensile strips for tensile strength (horizontal) and corrugated boxes for compression strength (vertical), this research analyzed the results from different patterns along the manufacturer's edge. These patterns were applied using various nozzle diameters to take glue volume into account. Key results indicate that in vertical strength, glue pattern and volume made no significant difference i.e. the low volumes were just as strong as the high volumes with no significant difference between patterns. As related to the horizontal strength, every pattern was significantly different yet all patterns demonstrated significantly increased strength with larger volumes of glue. From this study it was determined that depending on the product, a user should use a specific amount of glue to control costs and productivity. If the product is rigid and will not cause the package to bulge, then horizontal strength is not a key factor and a lower volume of glue is viable. If the product will cause the package to bulge, then horizontal strength is a key factor and a high volume of glue is required.

1. INTRODUCTION

CORRUGATED FIBERBOARD is a paper-based material consisting of a fluted containerboard sheet and at least one flat linerboard. It is widely used in the manufacture of corrugated boxes and shipping

*Author to whom correspondence should be addressed. Email: ksaha@calpoly.edu

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containers. Throughout the journey of a containerboard from the paper mills to box plants, which include the corrugated box plants and sheet plants, close quality control is provided to material properties such as basis weight, caliper, burst strength, water absorption, porosity to air and smoothness. Variations in material properties can affect the strength and performance of corrugated boxes.

Boxes from the corrugated fiberboard sheets can be formed in the same plant as the corrugator or alternatively, sheets of corrugated fiberboard can be shipped to a sheet plant for conversion into boxes. At both these facilities the corrugated board is creased or scored to provide controlled bending of the board. Slots are typically cut to provide flaps for boxes. The Regular Slotted Container (RSC, FEFCO 0201) is the most common style of corrugated box used in the industry [1]. All flaps for this style of construction are the same length and the outer (major) flaps meet at the center of the box. Figure 1 illustrates a box blank for a RSC style box as well as the folding and finishing process for creating a knocked down box.

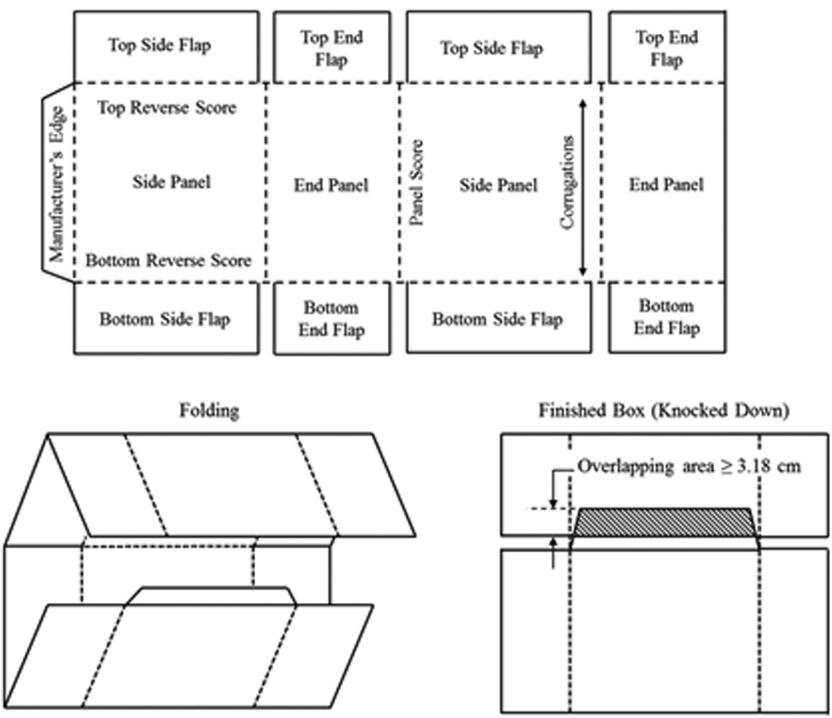

Figure 1. *Regular Slotted Container Blank and Finishing Process.*

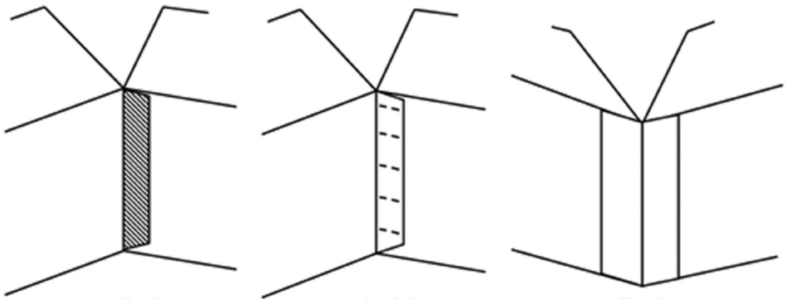

Figure 2. *Common Manufacturer's Joint Assembly Techniques.*

At the conversion plants, the two ends of the box blank are fastened together with tape, staples or adhesives (glue) for conversion to a box. The location at which these two ends meet is known as the manufacturer's joint. It may be noted that not all corrugated containers, such as bliss boxes, have manufacturer's joints. Figure 2 illustrates the common type of manufacturer's joints used by the industry. The glued and stapled joints may be assembled with the manufacturer's joint, whether on the inside or outside of the box, depending on factors such as continuity of graphics on the box, cube utilization while unitizing the containers and undisrupted internal space to avoid scuffing damage to the product.

The side panel thickness and paper basis weight commonly determine the kind of fastening technique used for manufacturer's joints. Adhesive joints are also referred to as "glued" joints in this paper. Glue and tape joints are most commonly used for most single wall constructions whereas, staples are frequently used for double and triple wall constructions.

Glued joints provide higher strength and rate of productivity, are better for rough handling, typically provide higher tensile strengths, do not interfere with printing when placed on the inside and offer lesser likelihood of scratching the product and personal injuries. They are the most economical method but can be messy in the manufacturing environment. They are also sensitive to temperature and humidity.

There are several regulations related to corrugated products such as those set by carriers (rail and truck), U.S. government (DOT, FDA, USDA, and EPA) and the Council of State Governments which provide guidelines regarding corrugated container construction [1,2]. More clearly defined specifications which can be considered as industry standards for corrugated materials are provided by the Fiber Box Association (FBA) or the Association of Independent Corrugators (AICC), and machinery and fabrication equipment guidelines and standards can be obtained from the Packaging Machinery Manufacturers Institute (PMMI) [3,4,5]. Although the tolerances provided by FBA and PMMI are voluntary, most corrugated manufacturing companies and many corrugated users consider these as specifications to be used when manufacturing or specifying most corrugated packaging.

The carrier rules provide the following guidelines for manufacturer's joints [1]:

Single and Double Wall Fiberboard Constructions: Boxes must have manufacturer's joints formed by lapping the sides of the box forming the joint not less than 3.18 cm, where the 3.18 cm is the actual overlapping or mating area (Figure 1). With regards to glued joints, these guidelines recommend gluing the entire area of contact with a water-resistant adhesive.

Corrugated shippers are designed to overcome the distribution environment hazards so that the products they carry reach the consumers, intact and ready for use. The transportation and warehousing hazards faced commonly by corrugated shippers include compression, shock, vibration, temperature, creep and humidity among others. Most material (containerboard) and corrugated package testing procedures are provided by the Technical Association of the Pulp and Paper Industry (TAPPI) and American Society for Testing and Materials (ASTM) [6,7,8,9].

When a shipping container is dropped during handling or compressed during stacking, its manufacturer's joint is subjected to stresses along with all other edges. The TAPPI Test Method T 813 om-04 (Tensile Test for the Manufacturer's Joint of Fiberboard Shipping Containers, Test Method) helps determine the strength of the manufacturer's joint of commercially made corrugated and solid fiberboard shipping containers and is applicable to taped, stitched, or glued joints which may also be used to evaluate laboratory fabricated joints similar to commercially made joints [6]. ASTM D 642 (Standard Test Method for Determining Compressive Resistance of Shipping Containers, Components, and Unit Loads) is commonly used for measuring the ability of the container to resist external compressive loads applied to its faces, to diagonally opposite edges, or to corners [8].

A study conducted in 1970 evaluated the amount of manufacturer's joint adhesive coverage of the glue flap required for satisfactory corrugated box performance and compared the performance of hot melt adhesives with that of regular aqueous adhesives used in the fabrication of manufacturer's joints for corrugated boxes. The laboratory tests performed towards these goals indicated equivalent glued joint tensile, joint Bathurst, box drop and box compression test values for the approximately 91 kgf, B-flute boxes fabricated with glued manufacturer's joints which varied between approximately 60–100% glue tab adhesive coverage. From the testing performed, the study also concluded that boxes fabricated with manufacturer's joints adhered with three or four beads of hot melt adhesive were equivalent in strength to boxes fabricated with regular aqueous adhesive glued manufacturer's joints.

A different study published in 1990, looked at the internal bond strength of the linerboard when glue was applied using an extruder applicator and flexo folder-gluers. Proper use of the extruder applicators was concluded to achieve full coverage of the glue lap and the adhesive viscosity and the amount of glue applied was recommended to be such that when the joint was made, the adhesive would spread out to give the 95% coverage specified. As related to flexo folder-gluers, if ply separation was a problem, the adhesive should be modified to give greater coverage and not deeper penetration.

Another recent study explored the compression and tensile strengths of RSC style corrugated boxes based on adhesive coverage, three different types of tapes (acrylic, paper and reinforced paper) and application angle of staples towards fastening on the manufacturer's joint. The results of this study suggested an overall higher tensile strength for glue than the other fastening techniques evaluated with no significant difference for peak force or deflection at peak force for all glued, stapled or taped treatments.

At present there is no data available to demonstrate the effect of variations in glue patterns as well as the glue bead diameter as related to the compression or the tensile strengths of corrugated boxes.

The objective of this study was to evaluate the tensile and compression strengths of corrugated fiberboard boxes as related to varying glue patterns and glue bead diameters.

2.0. MATERIALS AND METHODS

2.1. Glue Gun, Patterns and Nozzles

Champ 3™ Bulk Hot Melt Glue Gun (Glue Machinery Corp., Baltimore, Maryland, USA) with five nozzle attachments, 1 mm, 1.9 mm, 2.5 mm, 3 mm and 6 mm, were used. Four glue patterns, *dots*, *line*, *slashes* and *sine* were used in conjunctions with each nozzle (Figure 3).

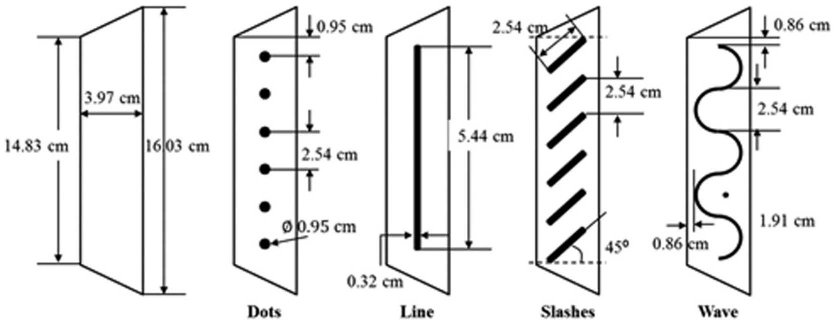

Figure 3. *Gluing Patterns Used in the Study.*

2.2. Corrugated Fiberboard Box

RSCs (FEFCO 0201) with inner dimensions of 39.85 cm × 29.69 cm × 13.97 cm were used in this study. C-flute corrugated fiberboard was used with a basis weight of 20/15/20 kg/ 92.9 sq.m. (44/34/44 lb/ 1000 sq.ft.), a bursting strength of 125 N/cm^2, and an edge crush test (ECT) of 79 N/cm. The manufacturer's edge dimensions are provided in Figure 3. All corrugated box samples used for this study were created using ArtiosCAD software and the Premium Line 1930 model of the Kongsberg table (Esko Graphics, Ludlow, Massachusetts, USA).

2.3. Manufacturer Joint Tensile Testing

TAPPI test standard T 813 om-04 (Tensile Test for the Manufacturer's Joint of Fiberboard Shipping Containers, Test Method) was used

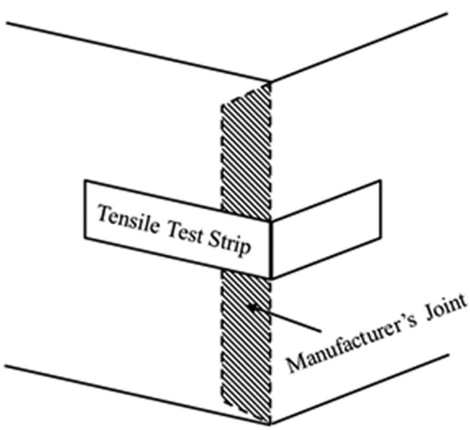

Figure 4. *Tensile Test Specimen Location.*

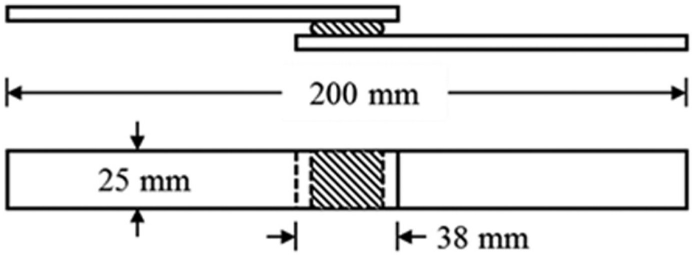

Figure 5. *Tensile Test Samples for Glued Joints.*

to compare the performance of various fastening methods for manufacturer's joints. This test gives an indication of the ability of the joint to withstand rough handling without failure, to the extent that failure is related to the tensile strength of the joint itself [6]. The initial jaw separation for the tensile tester was set at 180 ± 5 mm and the rate of separation used was 25 ± 5 mm/min. A Testometric tensile tester Model M350-5kN (Testometric Materials Testing Machines Company, Lancashire, United Kingdom) was used for all tests. Five glued specimens for each variable were tested after pre-conditioning for 24 hours at 50% relative humidity and 23°C.

Tensile test strips were prepared in accordance to TAPPI T 813 om-04 (Figure 5). The length of all samples was 200 mm and a width of 25 ± 0.5 mm was used.

2.4. Box Compression Strength Testing

The ASTM D 642 (Standard Test Method for Determining Compressive Resistance of Shipping Containers, Components, and Unit Loads) was used to test the compression strength [8]. The procedure is commonly used for measuring the ability of the container to resist external compressive loads applied to its faces, to diagonally opposite edges, or to corners. This test method is also used to compare the characteristics of a given design of container with a standard, or to compare the characteristics of containers differing in construction. This test method is related to TAPPI T 804 om-02 [7]. The tests were conducted using a fixed platen arrangement on a Lansmont compression tester Model 152-30K (Lansmont Corporation, Monterey, CA, USA), with a platen speed of 1.3 cm/minute and a pre-load of 22.68 kgf for zero-deflection in accordance with the standard. Five box samples for each variable were tested after pre-conditioning for 24 hours at 50% relative humidity and 23°C.

3.0. RESULTS AND DISCUSSION

For this research study the same grade of corrugated fiberboard, and glue type was used to construct boxes of a specific dimension as mentioned in section 2.2. The experimental treatments considered for this study were the nozzle diameters, and glue patterns, considered independent variables. To compare the performance of the various manufacturers joint prepared with different nozzle types and glue pattern, the compression strength of the box and the tensile strength of the glued joints specimens (Figure 5).

For the 5 different nozzle diameter and glue pattern the amount of glue (grams) varied considerably Figure 6. Corrugated boxes are used to convey a majority of finished goods, perishable and non-perishable, to retail outlets. A small percentage of decrease in glue volume can result in decreased costs and weight as well as faster throughput.

3.1. Tensile Strength of Glued Specimen and Compression Strength of Boxes

The results of the tensile strength of glued specimen (Figure 4) and compression strength of box are shown in Table 2. The statistical software package *Minitab* was used to perform an analysis of variance for the tensile strength and compression strength for the different nozzle diameters and glue pattern. Although compression strength testing provided both deflection and peak force, it was observed that the deflection data for the different treatments had a p value of > 0.05 compared to the compression strength data where the p-value < 0.05. Therefore this study focused on the ability of the containers to withstand compressive forces as effect of glue pattern and nozzle diameter. Since, the objective of this study was determine the effect of glue pattern and nozzle diam-

Table 1. Amount of Glue Used for Four Different Glue Patterns Using Four Nozzle Diameters.

	Glue Mass (g) for Nozzle Diameter				
Glue Pattern	**1.0 mm**	**1.9 mm**	**2.5 mm**	**3.0 mm**	**6.0 mm**
Dots	0.17 ± 0.12	0.33 ± 0.33	0.40 ± 0.40	1.03 ± 0.15	1.60 ± 0.00
Sine	0.3 ± 0.00	0.63 ± 0.63	0.67 ± 0.67	1.00 ± 0.10	1.43 ± 0.12
Line	0.5 ± 0.50	0.63 ± 0.63	0.73 ± 0.73	1.17 ± 0.06	1.37 ± 0.06
Slashes	0.33 ± 0.33	0.80 ± 0.80	1.00 ± 0.80	1.40 ± 0.20	1.93 ± 0.12

Table 2. Tensile and Compression Strength Results.

Nozzle (mm)	Pattern	Peak Tensile Force (N x 10^2)	Peak Compression Force (N x 10^3)
1.0 mm	Dots	0.408 ± 0.127	2.85 ± 1.27
	Sine	0.961 ± 0.402	3.14 ± 1.21
	Line	2.34 ± 0.365	2.34 ± 0.133
	Slashes	1.41 ± 0.485	2.34 ± 0.139
1.9 mm	Dots	0.707 ± 0.209	2.39 ± 0.133
	Sine	2.88 ± 0.826	2.53 ± 0.133
	Line	2.85 ± 0.741	2.40 ± 0.175
	Slashes	2.17 ± 0.328	2.52 ± 0.245
2.5 mm	Dots	1.36 ± 0.573	2.60 ± 0.323
	Sine	2.64 ± 0.331	2.45 ± 0.290
	Line	2.51 ± 0.980	2.26 ± 0.145
	Slashes	2.01 ± 0.753	2.39 ± 0.188
3.0 mm	Dots	2.53 ± 0.402	2.77 ± 0.186
	Sine	3.12 ± 0.484	2.37 ± 0.0904
	Line	3.49 ± 1.56	2.35 ± 0.244
	Slashes	2.49 ± 0.738	2.48 ± 0.0773
6.0 mm	Dots	3.24 ± 1.15	2.82 ± 0.166
	Sine	3.36 ± 0.670	2.26 ± 0.0752
	Line	3.93 ± 0.754	2.45 ± 0.0979
	Slashes	3.20 ± 0.755	2.74 ± 0.312

eter on the shear strength of the manufacturers joint the peak force required to disengage the glued area of a tensile strip was recorded rather than the force at break.

3.1.1. Box Compression Strength

For the compression strength analysis, the effect of glue pattern and nozzle diameter on peak force was the parameter of interest, and the interaction of glue pattern and nozzle diameter were considered as the predictors. The interaction of glue pattern and diameter was not found to be statistically significant (p-value = 0.220), thus, providing no evidence that the association between average peak force and nozzle diameter changed significantly for different glue patterns. Nozzle diameter was not a significant factor (p-value = 0.406) whereas the glue pattern was indicated to have some effect on the compression strength of the box (p-value = 0.071). It can be inferred that the compression strength

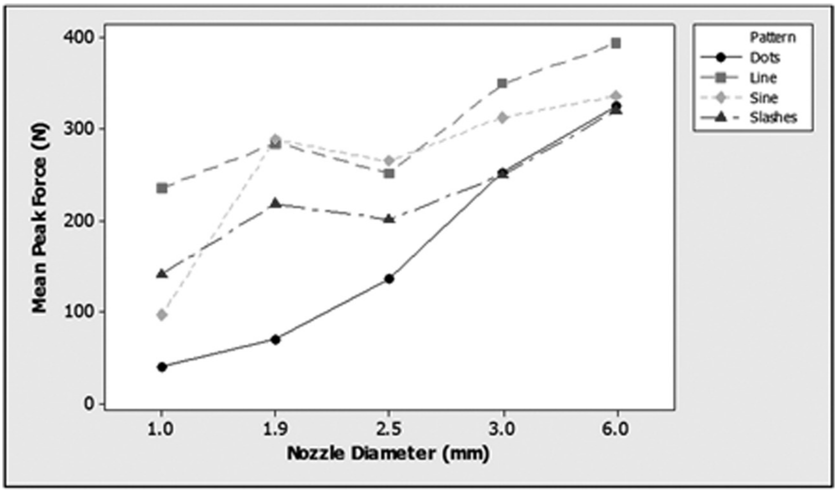

Figure 6. *Glue pattern and Nozzle interaction effect on Tensile Peak Force.*

of a box may not be compromised by changing the type of glue pattern or nozzle diameter to secure the manufacturers joint. Since a particular combination of glue pattern and nozzle diameter did not have a significant effect on peak force, it gives the box manufacturer the flexibility to reduce the amount of glue used by implementing a glue pattern and a nozzle type without sacrificing on the box compression strength. As indicated in Table 1 the glue pattern *dots* with a 1.0 mm nozzle diameter used 0.17 grams of glue compared to 0.30 grams for *sine* with a 1.0 mm nozzle diameter. This is twice the volume of glue without any significant increase in compression strength (Table 2). Therefore it can be suggested to select the glue pattern with the lowest volume in order to save material and reduce cost of manufacturing.

3.1.2. Tensile Strength of Glued Specimen

For the tensile strength analysis, the effect of glue pattern and nozzle diameter on peak force was the parameter of interest, and the interaction of glue pattern and nozzle diameter were considered as the predictors. It was observed that the tensile strength of the glued specimen was different from those of the compression strength results. Using an overall significance level of 0.05, the data provide evidence of a statistically significant effect of glue pattern and nozzle diameter (p-value < 0.001). As part of the post hoc analyses, we performed Tukey's pairwise comparisons. At an overall 95% confidence level, it was found that *line*, *sine*, and *slash* glue patterns yield significantly higher peak tensile force compared to dots. Similarly the *line* glue pattern has significantly higher tensile peak force than *slashes* (Figure 6). Also, it was observed that the mean tensile peak force is affected significantly by the glue pattern and nozzle diameter (Figure 7). The tensile strip samples prepared with a nozzle diameter of 1.0 mm had significantly lower tensile peak force compared to 3.0 mm and 6.0 mm. The best option that demonstrates the highest performance for tensile testing would be the *line* pattern with a 6.0 mm nozzle (Figure 6). However, the tensile peak force for specimen glues with a 3.0 mm nozzle and the *sine* pattern was similar to a *line* pattern and 6.0 mm nozzle ($p > 0.05$), suggesting material savings without sacrificing box performance (Figure 6).

The method used to make the tensile strips may have had an effect on these results. By gluing together the two rectangles as shown in Figures 4 and 5 and cutting out the strips, some strips may have had a disproportionate amount of glue. For example, the *dots* were applied at 1 inch increment which led to an area without any glue *dots*. Therefore, when the test strips were cut it was possible that only a portion of the *dot* pattern was present within the tensile test specimen. This could explain the low performance of the *dot* pattern. The results could have been different if there was a complete dot of glue within the glued area of the specimen. However in order to eliminate bias in the glue application method, the experimental design required that the specimens were cut from the boxes at random from the manufacturer's joint.

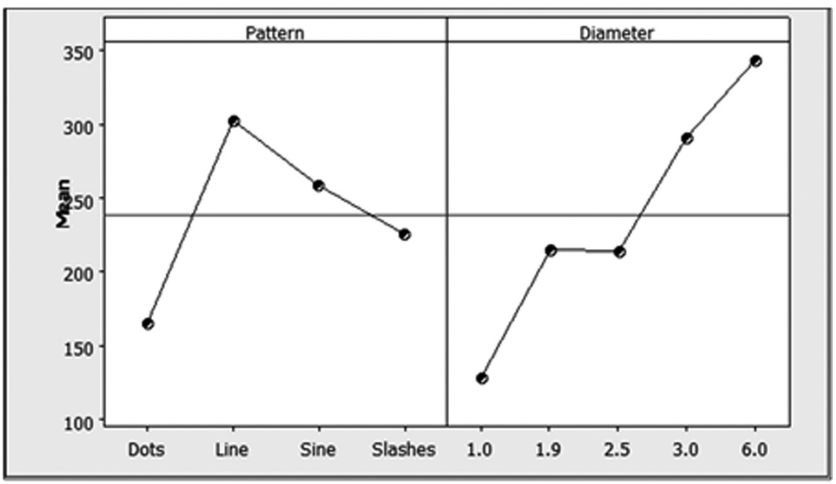

Figure 7. *Main Effects for Tensile Peak Force.*

3.2. Effect of Glue Pattern and Nozzle Diameter on Box Performance

Based on the statistical analyses of both the testing procedures the tensile testing (manufacturer joint) and the box compression strength, two different solutions can be provided for the best performing glue pattern with a specific nozzle diameter for a particular type of product. While comparing the compression strength of the boxes (Table 2) provides an estimate of a box's stacking strength, the tensile strength of the test specimens (Table 2) from the manufacturer joint provides the box's resistance to shear forces caused by bulging. Therefore there could be two solutions dependent on the needs of product-package system. If the product is a rigid structure that will not induce bulging from the inside and push the box outwards, then tensile strength of manufacturer joint specimen will not be a relevant measure of box performance, rather in this case the compression strength of the box would be better tool to evaluate box performance for stacking strength. Based on this reasoning it can suggest that the manufacturer joint of a box can be glued with a 1.0 mm nozzle with a *dot* pattern. Whereas if the product were to push outwards, then taking tensile strength into account will be necessary as opposed to the box compression strength, this would suggest constructing a manufacturer joint with the *line* pattern and 6.0 mm nozzle diameter. However a situation where the product-package system demands high compressive resistance as well as bulge resistance then the manufacturer joint can be glued with a *line* pattern and 6.0mm nozzle diameter. Since, there is no significant difference between the compression strength of boxes constructed with 3.0 mm and 6.0 mm nozzle, the manufacturer may select 3.0 mm nozzle to reduce the amount of glue, thus reducing material cost but bearing in mind that there could be some loss in bulge strength without any loss in compression strength.

4.0. CONCLUSIONS

The hypothesis that glue pattern could affect the strength of corrugated containers had never been studied previously. One hundred boxes were tested along with one hundred tensile strips to determine if indeed, glue pattern and amount made any significant difference in vertical compression strength and bulging of a corrugated container. Statistical analysis indicated that the *p-value* was greater than 0.05 for compression strength analysis therefore it can be inferred that regardless of glue pattern or nozzle diameter less than 3.0 mm (thus volume) compression strength of a box will not be affected. Whereas after analyzing the tensile strength data, the *p-value* were 0.00, suggesting that the glue pattern and nozzle diameter had a significant effect on the tensile peak force of manufacturer's joint of a box. Upon further, statistical analysis, it was determined that in general the more glue used resulted in higher tensile strength with increasing nozzle diameter for all the glue patterns. Also, irrespective of the nozzle diameter the *line* pattern indicated to be the best option to construct a manufacturer joint which could sustain high bulging forces. Thus it can be suggested that a manufacturer joint glued with line pattern with a 6.0 mm nozzle will have the highest resistance against bulging forces. However, the box manufacturer should be aware that if there are minimal bulging forces exerted by the product on the manufacturer joint, it would be possible to use a low volume of glue with 1.0 mm and *dot* pattern to save material and reduce cost.

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Knowledge Resources and Firm Performance: A Packaging Industry Perspective

NATHANIEL C. ELSER[1], DR. JUDD H. MICHAEL[2,*], DR. MARK A. GAGNON[3] and DR. CHARLES D. RAY[1]

[1]*Department of Ecosystems Science & Management, The Pennsylvania State University, University Park, PA 16802*

[2]*Department of Ag & Biological Engineering, The Pennsylvania State University, University Park, PA 16802*

[3]*Department of Ag Economics, Sociology and Education, The Pennsylvania State University, University Park, PA 16802*

ABSTRACT: Manufacturers can compete based on a variety of factors ranging from plant and equipment to intellectual property. Packaging producers may be tempted to rely on their capital or technological assets for competitive advantage, when in fact they may be better off making greater investments in their knowledge resources. Previous research has shown that knowledge resources associated with a firm influence both its performance and competitiveness. However, the extent to which these knowledge resources promote or hinder firm performance can differ by industry context and much of this research has been conducted with fast-paced industries. Understanding how specific types of knowledge resources relate to performance in a given industry can be valuable to business practitioners operating within that industry and we therefore conducted a project to examine these relationships in a key segment of the packaging industry. We utilized a survey of managers in the transport packaging segment to measure both the knowledge resources available to firms, as well as the value provided by those resources in terms of firm performance. Results suggest that firms having high levels of knowledge resources perform better than those lacking such resources.

1. INTRODUCTION

SUBSTANTIAL research has been conducted on various performance-related aspects of the packaging world. Focal areas have ranged from performance of materials [23] to optimizing packaging-related processes and operations [9] to logistics and the supply chain [30,18],

*Author to whom correspondence should be addressed. Email: Packaging@psu.edu

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yet few works have been published which examine the performance of companies involved in the packaging industry. Exceptions include research utilizing packaging firms as examples in performance-related works (e.g., environmental performance, [20]), and research investigating manufacturing performance of packaging producers [19].

We believe that greater emphasis should be placed on investigations of firm performance in this important industry. Understanding the factors that can increase a firm's performance or profitability has been an area of considerable emphasis for management science scholars. A goal with this type of research would be to identify such factors and then make suggestions regarding areas that business leaders should change within a specific organization or sector of the overall industry.

One popular management theory is that individual firms can be distinguished by their own unique collection of resources and capabilities, and that these resources have a direct impact on performance. If this is true then some firms should be able to gain competitive advantage through proper leveraging of their specific collection of resources and, ultimately, earn returns greater than their competitors [10]. Examples of resources may include employees, access to capital, machinery and equipment, intellectual property, etc.

Our research therefore sought to investigate the potential existence of a knowledge-to-performance relationship in a packaging industry setting. Specifically, this project attempted to identify firm-related knowledge resources that may be correlated with performance in North American transport packaging producers. As we discuss below, knowledge resources are an acknowledged source of competitive advantage in a variety of contexts and should therefore be a variable of interest for packaging practitioners and researchers.

Our research focused on knowledge-based resources internal to the firm, specifically market and technological expertise. Wiklund and Shepherd [33] argue that knowledge associated with markets and technology can increase a firm's ability to discover and exploit new opportunities and hence lead to better performance. Our research builds on past works with firms in various industries, such as film studios [17], law firms [11] and textile manufacturers [24] that have shown a positive relationship between knowledge resources and firm performance.

No known previous work has examined this particular factor as a potential influencer of performance in a sample of packaging producers. Another justification for this work is that understanding the value of different types of knowledge can be beneficial in strategic decisions involving the acquisition and allocation of resources. Furthermore, understanding how a firm's knowledge resources influence its competitiveness can help facilitate managerial decisions related to, for example, the recruitment, retention, and training of employees [28].

2.0. BACKGROUND

Firms competing in the same industry will often face very similar environmental conditions. This, however, does not imply that each firm has available the same resources on which strategic decisions, in response to those conditions, can be made. Nor does the availability of similar resources mean that each firm is capable of responding with similar efficacy. The observation that seemingly very similar firms can differ substantially in terms of both strategies and performance has led to an immense and growing body of research that seeks to better understand and identify those factors most influential to firm-level outcomes.

One promising line of investigation by management scientists is that the knowledge held within firms can serve as a unique resource and have a direct impact on organizational outcomes. Put more succinctly, there is increasing evidence that firm-specific knowledge can be a highly valuable source of competitive advantage [32]. Support for this relationship has been shown in a variety of specific instances, including how within-firm knowledge that is related to markets and technology can increase a firm's ability to discover and exploit new opportunities [33]. However, much of the past work in this area has been done on growing or high-tech industries in which the effects of knowledge on firm-level outcomes may differ from those in a more mature industry setting such as transport packaging.

2.1. Value of Knowledge Resources

Two of the most promising types of firm knowledge being investigated today are market and technology based knowledge, and they formed the basis for our investigation. According to Burgers and colleagues, "technological knowledge refers to knowledge associated with products, technologies and/or processes," whereas "market knowledge refers to knowledge associated with targeting customer sets, entering markets, distribution channels, marketing approaches and business models" ([2], p. 56).

There are multiple ways that market and technology based knowledge can have value for a company. These can range from facilitating the innovation process [33,2] to allowing a firm to quickly exploit an identified opportunity or rapidly respond to competitors' advancements [3,33]. For example, a pallet manufacturing company having expertise in information technology may utilize that knowledge to provide logistical services for its customers. A firm having technological expertise may more easily discover and adopt new production processes, thus leading to gains in efficiency. This same knowledge could also allow for the creation of new products through the utilization of new materials, and as a result allow new options for raw materials [25,26]. For a packaging producer, knowledge of alternative materials such as bioplastics could allow it to increase the variety of products offered and make it less vulnerable to the markets of any single raw material.

2.2. North American Pallet Industry

The pallet industry serves as an appropriate venue for our study not only because of its importance as a critical component of most supply chains [21], but also due to recent trends and developments. Although the pallet manufacturing industry may seem relatively stable, it has experienced important changes that are worth mentioning. Major trends of the past few decades include: a growing preference for block pallets among large retailers, new regulations for packaging materials involved in international trade (e.g., ISPM [15]), the growth of pallet reuse and recycling [1], and the rise in power of large pallet pooling organizations [29]. Moreover, parts of the supply chain are increasingly demanding that their transport packaging providers make technology-based solutions (e.g., RFID capabilities) available as part of the unit load solution.

Considering these ongoing developments, knowledge of markets and technology may become increasingly valuable resources on which successful industry firms will depend. Such specialized knowledge can increase early awareness of new trends or changes in the industry, potentially resulting in a source of competitive advantage [33]. In addition to this, the knowledge resources available to a firm may dictate the strategy it pursues in response to these market and technological changes [2].

3.0. RESEARCH METHOD

The research instrument used to collect data for this study was a survey questionnaire administered electronically via the internet. To increase validity and ensure contextual suitability, a panel comprising both management scholars and industry experts was asked to review the survey and provide feedback. Working with a statistician in the social sciences, we tested the intended survey instrument to ascertain the quality of the data it collected, and to ensure that the instrument was conducive to data processing and analysis [8,14]. Following these reviews, a series of small pilot tests were run in which the electronic version of the survey was completed online by multiple people to ensure the website functioned properly.

An initial email was sent by the president of the National Wooden Pallet and Container Association (NWPCA) in January 2012 to known upper-level managers of 1,192 firms, including both NWPCA members and non-members with pallet-related operations. The association's list had been filtered such that only company contacts that included a name (and associated email address) of an upper-level manager (e.g., owner, president, vice president, etc.) were included in the survey. The survey's instructions stated that only the person receiving the correspondence should complete the survey.

The email provided a brief description of the study and included a link to an online questionnaire to be completed by the recipient. A follow-up email was sent by the NWPCA 10 days later as a reminder and the researchers subsequently sent personalized emails to nonrespondents in the following two weeks as a final request for their participation [7].

3.1. Measures Used

Measuring firm performance and its antecedents can be a challenge for researchers given the wide variety of firm operations, economic conditions, managerial goals, etc. For example, performance is commonly viewed as a multidimensional concept [15], and so the relationship between performance and other variables may depend upon the indicators used to assess performance, including both financial and non-financial measures. This research therefore used performance and knowledge measures commonly validated in entrepreneurship and management research.

3.1.1. Dependent Variable

Performance was our dependent variable and was assessed using both financial and non-financial measures as described by Wiklund and Shepherd [33]. Respondents were asked to compare their firm's performance over the past three years to that of their most relevant competitors for five different dimensions of performance: sales, number of employees, profitability, product/service quality and customer satisfaction ($\alpha = .80$). Five-point Likert scales ranging from "much weaker" to "much stronger" were used. All five dimensions were equally weighted and used to calculate an aggregate score representing an overall measurement of each firm's performance (i.e., the performance construct).

3.1.2. Independent Variables

As discussed, results from previous studies have supported the existence of a relationship between a firm's performance and the knowledge resources it has available [33]. For this study, we used a modified version of Wiklund and Shepherd's [33] scale to assess firm knowledge by asking respondents to compare their firm's knowledge position on 11 individual items relative to other companies within their industry ($\alpha = 0.91$). The items, measured on a five-point Likert scale similar to that used for performance, addressed knowledge related to marketing, technology and company management. In addition to the individual item measures, each firm was also given a combined aggregate score representing their overall bundle of knowledge resources. Only those firms whose respondent completed all 11 items were given the combined aggregate score. This aggregate score equally weighted each measure and was used to represent the firm's overall bundle of knowledge resources.

3.1.3. Additional Variables

Our survey collected additional data relating to firm size, revenue and age. These were tested for use as control variables.

4.0. RESULTS

4.1. Respondent Profile

The identified population of interest for this study consisted of firms headquartered in North America whose primary source of revenue came from the production of new wood pallets or the recycling, repair and/or remanufacturing of wood pallets. We received 183 usable surveys; after removing those from firms headquartered outside of North America, or whose primary source of revenue came from non-pallet manufacturing activities such as wholesaling, leasing, logistics and primary wood processing, the usable sample consisted of 133 responses. This represented an effective response rate of 11.2 percent.

Even though these data were not meant to reflect the entire industry, we utilized common statistical tests to look for potential limitations due to nonresponse bias. We evaluated the mean responses of survey measures for those managers who completed the survey prior to the stated deadline and those who completed the survey after the deadline had passed. The perceptions of late respondents are assumed to be more similar to those of non-respondents than those of early respondents [12], and so significant correlations between item measures and the survey completion date would point to the existence of nonresponse bias [4]. Using t-tests, we compared the mean responses of these two groups for multiple variables, including number of employees, firm age, total revenue in 2011, total performance score and total knowledge score. The results of these tests indicated that early respondents did not differ significantly from late respondents for any of the chosen variables ($p < 0.001$), thereby mitigating concerns of potential nonresponse bias [27].

Of the respondent firms, 120 were headquartered in the United States, nine in Canada and four in Mexico. Sixty-five percent of the 133 identified their primary source of revenue as being from the production of new wood pallets; the remaining 35 percent were from the recycling, repair and/or remanufacturing of wood pallets. The mean age of respondent firms was 34 years. All but five respondent firms had less than 250 employees, with nearly 60 percent having fewer than 50 employees. Finally, the total revenue for about 45 percent of respondent firms in 2011 was less than $5 million; 43 percent had revenues between $5 million and $25 million while nine percent had revenues greater than $25 million. Five firms did not respond to the revenue item.

Questions pertaining to business activities, product offerings and methods of waste utilization were included in the survey. These results suggest that the average pallet producer is diversified, pursuing a variety of revenue-producing activities. For example, in addition to their primary source of revenue, 66 percent of firms responded as being involved in at least two other business activities such as brokering/wholesaling, third party logistics and pallet recovery/disposal (Table 1). Pallet remanufacturers were significantly more likely to be involved in third party logistical services than were new pallet producers ($p < 0.01$).

Table 1. Summary of Business Activities Involved In, by Industry Group.

Business Activity	New	RRR[a]	Total
Producing new wood pallets	87 (65.4%)	37 (27.8%)	**124 (93.2%)**
Brokering/Wholesaling	34 (25.6%)	21 (15.8%)	**55 (41.4%)**
Pallet recovery/disposal	46 (346.%)	38 (28.6%)	**84 (63.2%)**
Third party logistics	8 (6.0%	12 (9.0%)	**20 (15.0%)**
Pallet leasing/rental systems	2 (1.5%)	5 (3.8%)	**7 (5.3%)**
Recycling, repairing and/or remanufacturing wood pallets	50 (37.6%)	46 (34.6%)	**96 (72.2%)**
Primary wood processing (sawmill)	16 (12.0%)	6 (4.5%)	**22 (16.5%)**
Other	16 (12.0%)	5 (3.8%)	**21 (15.8%)**

[a]Recovery, repair and/or remanufacturing

Note: Row and column totals will not sum to 100% due to calculation methods (i.e., 124 = 93.2% of the total sample of 133)

Regarding the types of pallets respondent firms regularly sell, nearly all marked stringer, 62 percent marked block, 29 percent marked plywood, 24 percent marked panel deck, 12 percent marked non-wood (plastic, steel, etc.) and six percent marked wood composite/corrugated (Table 2). Nearly 40 percent of respondent firms regularly sell at least three different pallet types.

4.2. Knowledge and Performance

We divided the sample into two groups based on the overall performance scores of the firms; this split sample allowed us to investigate the relationship between knowledge resources and firm performance. We first calculated the mean performance score of the entire sample ($\bar{x}$

Table 2. Summary of Pallet Types Regularly Sold by Industry Group.

Pallet Type	New	RRR[a]	Total
Stringer	85 (63.9%)	46 (34.6%)	**131 (98.5%)**
Block	57 (42.9%)	26 (19.5%)	**83 (62.4%)**
Panel deck	28 (21.1%)	4 (3.0%)	**32 (24.1%)**
Plywood	32 (24.1%)	7 (5.3%)	**39 (29.3%)**
Wood composite, corrugated	7 (5.3%)	1 (0.8%)	**8 (6.0%)**
Non-wood (plastic, steel, etc.)	7 (5.3%)	9 (6.8%)	**16 (12.0%)**
Other	3 (2.3%)	0 (0.0%)	**3 (2.3%)**

[a]Recovery, repair and/or remanufacturing

Note: Row and column totals will not sum to 100% due to calculation methods.

= 3.76). We then compared the overall performance score of each firm, calculated as an aggregate measure of the five equally weighted performance items, to the mean performance score of the entire sample. Firms whose overall performance scores were greater than the mean performance score of the entire sample were categorized as high performers, whereas those whose overall scores were lower than the sample mean were categorized as low performers.[1] The mean scores of the high performance group and low performance group were ($\bar{x}$ = 4.25) and ($\bar{x}$ = 3.35), respectively. The size of the high performance group was (n = 59), whereas the low performance group was (n = 69). Five respondent firms failed to complete all the performance items and thus were not included in either performance group.

To differentiate the knowledge resources of high performing firms from those of low performing firms, analysis of variance procedures comparing the performance groups were carried out on each individual knowledge item. These procedures were also carried out on the total knowledge score, which was calculated as an aggregate measure of all 11 equally weighted knowledge items. We only included those respondent firms that completed all 11 knowledge items when calculating this measure. Descriptive statistics for each knowledge item and the total knowledge score for both performance groups are given in Table 3.

Our data illustrate that the high performers differ significantly from the low performers in terms of the overall bundle of knowledge resources they have available to them ($p < 0.000$). Furthermore, this difference remains significant for each of the 11 individual knowledge measures, albeit not all at the same level.

5.0. DISCUSSION AND CONCLUSIONS

This exploratory project was undertaken to help industry leaders better understand the value of knowledge resources as they relate to firm performance. Finding the answer to why one firm is performing better, or worse, than its competition should be one of the most important quests of company leadership. A primary objective of this research was to identify those types of knowledge resources that may be related to firm performance in the North American transport packaging industry. We sought to determine if firms in the industry could benefit from the development or acquisition of specialized knowledge related to mar-

[1]Tests comparing the lowest 1/3 and highest 1/3 of performers showed statistically similar results and therefore are not included here.

Table 3. Descriptive Statistics and ANOVA Results Between Performance Groups.

Knowledge Measure	Perf. Group	n	Mean	Std. Deviation	F	Sig.
Expertise regarding company management	Low	68	3.72	0.878	35.191	0.000
	High	56	4.52	0.539		
Staff with a positive commitment to the company's development	Low	67	3.76	0.872	24.223	0.000
	High	58	4.45	0.654		
Expertise regarding development of products or services	Low	69	3.59	0.828	14.959	0.000
	High	57	4.16	0.797		
Staff educated in giving superior customer service	Low	68	3.93	0.852	11.842	0.001
	High	56	4.41	0.682		
Technical expertise in pallet design	Low	68	3.74	0.924	8.050	0.005
	High	56	4.18	0.789		
Staff who like to contribute with ideas for new products/services	Low	67	3.51	0.766	7.764	0.006
	High	57	3.91	0.851		
Working knowledge of information systems technology	Low	65	3.18	0.864	24.475	0.000
	High	57	3.95	0.833		
Staff capable of effectively marketing your products/services	Low	68	3.25	0.904	21.374	0.000
	High	57	3.98	0.855		
Technical expertise in manufacturing systems	Low	67	3.51	0.959	4.425	0.037
	High	58	3.84	0.812		
Proficiency in procuring and sourcing materials	Low	69	3.61	0.861	6.357	0.013
	High	56	3.98	0.774		
Expertise in marketing	Low	67	3.16	0.846	13.837	0.000
	High	54	3.76	0.910		
Total Knowledge Score[a]	**Low**	**60**	**3.5530**	**0.59538**	**29.472**	**0.000**
	High	**49**	**4.1373**	**0.51060**		

[a]Includes only those respondents who answered all 11 knowledge items.

kets, technology and management. While the research design prevents us from concluding causality, we can suggest that, in our sample, firms which performed at higher levels than their competitors simultaneously had greater knowledge resources.

Results from this study offer further evidence to support previous research [33,28,27] highlighting the link between a firm's knowledge resources and its performance. Although of a relatively simplistic research design, the results shown here provide support for the existence of such a relationship. We do, however, acknowledge that other factors are likely involved in this relationship [28]. For the reasons mentioned above, it is likely that firm knowledge enhances opportunity identification abilities, thereby facilitating innovative processes and ultimately encouraging greater performance. Studying this or other similarly complex relationships, however, was outside the realm of this research.

Due to the statistically significant difference between high and low performers on each individual knowledge item, we did not identify any single type of knowledge that can be deemed irrelevant or detrimental in its relationship to performance. Nonetheless, the results may justify further consideration of some particular items. For instance, measures of manufacturing systems and pallet design expertise, although still significant at ($p < 0.05$) and ($p < 0.01$) respectively, were among those that differed least between high and low performers. This relatively low variance may indicate such firm knowledge is less than vital to firm performance, or that nearly all of these producers utilized NWPCA's Pallet Design System (PDS) and hence it is not a differentiating factor.

Expertise regarding company management had the highest mean score among all knowledge items for the top half of performers ($\bar{x} = 4.52$), while having only the fourth highest mean score among all knowledge items for the lower half of performers ($\bar{x} = 3.72$). As a result, it was also among those knowledge items that differed most between the two groups ($p < 0.000$). This may have important implications for many industry firms, suggesting managerial knowledge is one of the most valuable assets.

The mean scores of the item pertaining to expertise in marketing may reflect a similar situation within the industry. Although showing significant variance ($p < 0.000$), the mean scores were the lowest among all knowledge items for both the high performance group ($\bar{x} = 3.76$) and low performance group ($\bar{x} = 3.16$). Again, firms may not feel the need to invest in this specialized knowledge, feeling comfortable pursuing a "business as usual" marketing strategy. Such a strategy may seem sufficient for the lower performers if they perceive their products as commodities, having few aspects on which they can differentiate their products from those of their competitors.

5.1. Limitations

Although utilization of an online questionnaire is advantageous in many aspects, the potential of methodological bias common in self-administered surveys could present limitations in the research findings. Our use of an online questionnaire, self-reported data and subjective measures all create potential for error. To minimize this potential, we used measurement scales having been previously validated in the literature. We also followed generally accepted methods for data collection and analysis procedures.

While self-reported data may offer greater flexibility in terms of measuring various organizational characteristics, “such measures may be subject to bias because of social desirability, memory decay, and/or common method variance” ([22], p. 765). However, previous research has suggested that subjective measures, such as those assessing firm performance, can accurately reflect objective measures, and so enhance validity [6].

Our research design also prevents us from determining causality in the relationship between knowledge resources and performance. Although our findings are in agreement with previous studies, we acknowledge that untested factors are also likely related to firm performance. The limited size of the sample population also prevents us from generalizing to the entire industry; we would remind readers that the purpose of this project was not to characterize the state of the entire pallet industry. As the study was exploratory in nature, we hope our findings may encourage others to investigate the relationship between knowledge resources and performance in other sectors of the packaging industry.

5.2. Conclusions

As packaging continues to play a more critical role in the marketing, safety, and logistics of products [5,16,31], and as environmental concerns related to packaging become even greater [13], it would seem relevant to learn as much as possible about various performance-related aspects of the firms that actually make packaging products.

Previous research has shown that knowledge resources associated with markets and technology positively relate to firm performance [33]. Knowledge of this kind may prove valuable because it can support and enhance the innovative processes of a firm. In addition, understanding the needs of both current and potential customers may facilitate the identification of opportunities.

Results from this study reinforce the previous findings and suggest that transport packaging firms having greater knowledge resources perform better than their competitors. Industry executives may opt to acquire specialized knowledge through recruitment activities, develop knowledge resources through training programs, or invest resources elsewhere depending on their strategic objectives [28]. Alternatively, firms may choose to develop new methods for managing their current knowledge resources in an effort to utilize them more effectively. The results of this study, along with those of previous research, suggest that industry practitioners should take seriously the value associated with their firm's knowledge resources.

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Modeling Headspace Pressure in Retortable Packages

SRAVANTI PALURI[1,*], ARTHUR A. TEIXEIRA[2] and BRUCE A. WELT[2]

[1]*Master of Science Thesis Candidate, Department of Chemical Engineering, PO Box 116005, Gainesville, FL 32611-6005 USA*

[2]*Professor, Department of Agricultural and Biological Engineering, IFAS, Frazier Rogers Hall, PO Box 110570, Gainesville, FL 32611-0570 USA*

ABSTRACT: Flexible packages, a new attraction in the market for shelf-stable canned foods, are more susceptible to damage during thermal processing for sterilization. In order to maintain package integrity, it is important to keep the pressure differential across the package walls at a minimum. The purpose of this study was to confirm a hypothesis that the disagreement between measured and predicted pressures during retort come up time reported in a previous study was caused by the positioning of the temperature sensor (bottom of the module), while pressure buildup was driven by temperature in the headspace at the top of the module. In this study, experiments were carried out to predict internal pressure in the headspace of a rigid pressure-tight module that withstood variations in temperatures and pressures. A stainless steel module was custom-made with a reseal-able lid, provisions for thermocouples, an inlet valve from which to pull vacuum, and a dial gauge to measure headspace pressure. The module was instrumented so as to measure and record the temperature profile at two different locations, one near the top and one near the bottom of the module, while undergoing thermal processing in a retort. For each set of experiments, three food systems were used to fill the module; pure distilled water, 5% saline solution and 10% sucrose solution. A mathematical model was used to predict the headspace pressure profile in response to two experimentally measured temperature profiles at top and bottom of the module. Results from these studies were compared with results from earlier work to account for the error between experimental and predicted headspace pressure profiles found in that work. They showed that differences between predicted pressures from top and bottom temperatures in this study, and differences between measured and predicted pressures found in the previous work followed similar patterns and were of the same order of magnitude. These findings supported the hypothesis that disagreement between measured and predicted pressures found in the previous work was likely due to the reason that the temperatures used to predict pressures were measured at the bottom of the module, while the measured pressure was generated in response to head space temperature at the top of the module.

*Author to whom correspondence should be addressed.

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PRACTICAL APPLICATION

MODELS for internal headspace pressure will lead to better control and knowledge of overpressures required to minimize differential pressure during thermal processing. Thus, modeling headspace pressure will avoid damage to the flexible packaging and maintain the quality and safety of food.

1. INTRODUCTION

The technology of packaging food in cans, jars and other rigid containers has now expanded to encompass shelf stable foods in flexible packages. Flexible packages offer advantages of lower storage space and lighter weight when compared to rigid glass or metal containers. They may be in the form of flexible bags and pouches or semi-rigid trays and bowls. An important attribute of flexible packaging is its ability to form thinner, lighter, more compact packages [1]. Products in flexible packages require less heating time to achieve commercial sterility, and thus retain better quality with lower processing cost [2]. While being processed under high temperature and high pressure conditions in a retort, flexible packages may suffer damage to walls and seals from excessive pressure internal pressure, requiring careful control of overriding air pressure during retort processing.

1.1. Background

During thermal processing in the retort, internal pressure is built-up in the headspace of sealed packages. This internal pressure is caused by internal water vapor and entrapped gases expanding in response to increasing temperature. At high temperatures, the solubility of gases in the solution decreases, and they are released into the headspace of the package. The entrapped gases in the headspace consist primarily of the released gases and residual air. This internal pressure may be greater than the saturation pressure of the steam in the retort. If the internal pressure is greater than retort pressure, the package may swell or burst, and if it is lesser, the package will indent or collapse. The increasing internal pressure in a flexible package must be continuously counterbalanced by providing external pressure. This external pressure can be provided by the introduction of compressed air along with saturated steam in the retort.

In order to keep the pressure differential across the package at a minimum, internal pressures must be known or estimated. In most cases, a trial and error approach is followed to determine optimum overriding air pressures. Mathematical modeling of internal headspace pressure could reduce this element of uncertainty as well as time and cost, thus, becoming a useful tool to predict optimal overriding air pressures during thermal processing. The quest for such models has been the subject of much previous work described below.

1.2. Previous Work

Pascal *et al.* addressed the effects of pressure differential on seal strength and sensitivity of package wall to changes in headspace volume, but did not make any attempt to mathematically predict internal headspace pressure in response to temperature [3]. Ghai *et al.* (2011) presented a good review of the literature on attempts to mathematically predict internal headspace pressures [4]. This review served as background for his attempt to develop a mathematical model for predicting internal pressure in the headspace of a rigid pressure-tight module during thermal processing. His model predicted internal headspace pressure in response to the internal temperature of the product during retort processing under specified initial and boundary conditions. His model was based on the equation of the International Association for Properties of Water and Steam (IAPWS) to estimate vapor pressure of water and was coupled with the Ideal Gas Law for distilled water, along with Raoult's Law for saline and sucrose solutions. Results from his work revealed some disagreement between predicted and measured pressures during retort come-up time as can be seen in Figure 1 for distilled water. Results for saline solution (5%) and sucrose solution (10%) were similar.

1.3. Rationale and Objective

Our hypothesis was that the disagreement between the measured and predicted pressures during retort come up time by Ghai *et al.* (2011) was caused by positioning of the temperature sensor at the bottom of the module, while pressure buildup was driven by temperature in the headspace at the top of the module. Therefore in the work reported here, temperature was measured and recorded at two different locations (top and bottom) inside a stainless steel module of the same size and de-

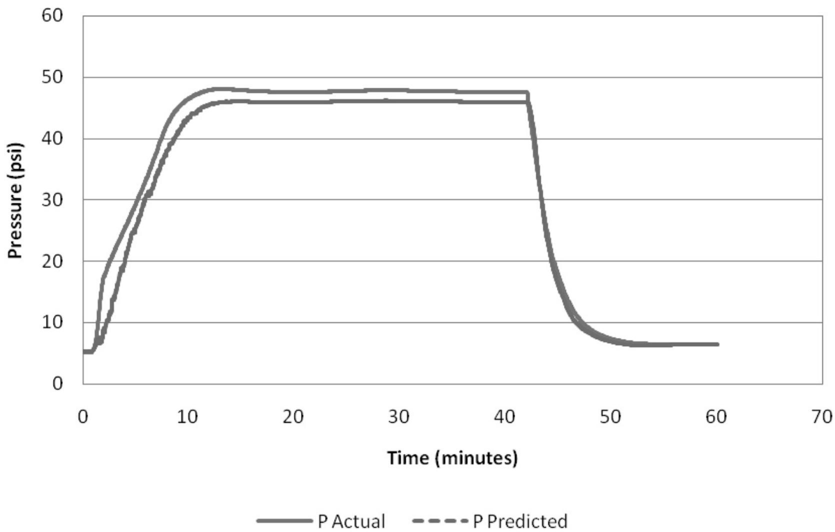

Figure 1. *Comparison of measured and predicted internal pressure profiles for distilled water by Ghai et al. (2011).*

sign as that used by Ghai *et al.* (2011) during thermal processing in a still-cook pilot plant retort. The objective of this work was to compare the difference in pressure profiles predicted from the top and bottom temperature profiles with differences between predicted and measured profiles reported by Ghai *et al.* (2011).

2. PROCEDURE

2.1. Fabrication and Design of Module

A pressure-tight cylindrical module was fabricated in the Agricultural and Biological Engineering Department machine shop at the University of Florida. The material of construction was food-grade stainless steel to avoid chemical reactions with the contents at elevated temperatures. The module was made to be pressure-tight to a safety factor of 3. The module consisted of two separate pieces, a cylindrical body and a separate circular lid piece as shown in Figure 2. The cylindrical body had an inner diameter of 7.1 cm, a height of 10.9 cm and a wall thickness of 0.4 cm, enclosing a volume of 430 ml. It also contained two holes in the side wall, one near the top and the other near the bottom to accommodate thermocouples. Two K-type thermocouples were inserted horizontally through the holes in the body of the module to reach the center line and permanently sealed. One of these was 0.6 cm from the top of the body and the other was 1.0 cm from the bottom, leaving the two thermocouples 8.6 cm apart. The cylinder

bottom also had a flange to accommodate bolts on the lid for a pressure-tight seal. The lid was fabricated to fit over the body with an O-ring gasket, and had two holes in the center to accommodate a dial gauge to measure internal pressure and an inlet valve through which to draw vacuum. An Ashcroft® pressure gauge was installed to easily check for the pressure-tight nature of the lid. The vacuum inlet had a stainless steel ball valve leading to a connection with a tube from the vacuum pump to pull vacuum into the module. The module was first tested on the bench-top to ensure proper functionality and no leakage.

2.2. Experimental Set-Up

The next task was to measure and record internal temperatures during triplicate pilot plant retort runs for each of the three aqueous solutions: pure distilled water, saline solution (5%) and sucrose solution (10%). The experimental set-up consisted of the pressure-tight module, vacuum pump steam retort, and data acquisition system (Figure 3). The volume of solution in each run was 410 ml, maintaining a constant headspace of 8mm. Vacuum was drawn with a 1/3 horse power Emer-

Figure 2. *Stainless steel module used to record temperatures at top and bottom during retort processing.*

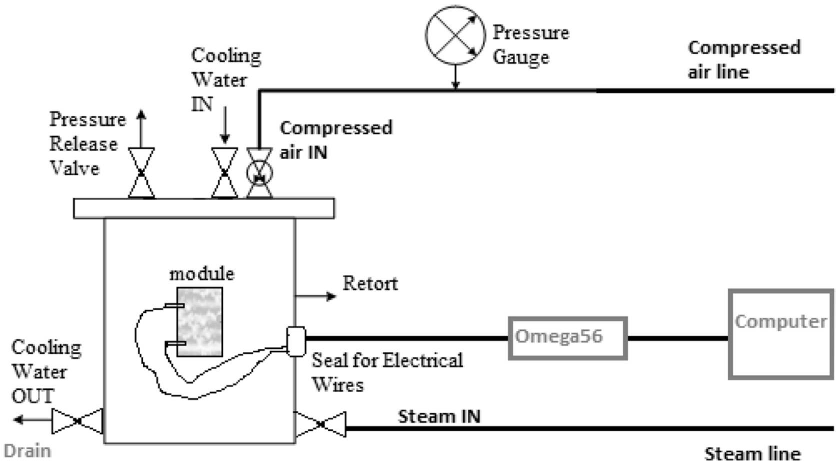

Figure 3. Experimental set-up for retort processing experiments with data acquisitions system.

son® vacuum pump to 15 inches Hg (~0.5 atm or 50.8 kPa). The module was placed inside a pilot scale still cook steam retort in the Food Science and Human Nutrition Department Pilot Plant at the University of Florida. The retort was equipped with a mercury-in-glass (MIG) thermometer and a pressure gauge to enable external monitoring of temperatures and pressures. A total of three lead cables passed through the packing gland on the retort, two for thermocouples inside the module and a free thermocouple outside the module within the retort for recording retort temperature. Thermocouple lead wires were connected to an Omega® 56 data acquisition system (DAQ) which, in turn, was connected to a computer containing the necessary software to capture and record temperature data in real-time.

2.3. Design and Execution of Experiments

Prior to conducting experimental runs, the three thermocouples were calibrated within the steam retort while operating at process temperature, and adjusted to agree with the MIG. Thermal processing tests were run for 10 minutes at 121°C (250°F). Three replicate runs were carried out on each aqueous solution, with initial conditions for each system as follows:

Distilled water was used first, being the simplest food system, and as the baseline for experimental runs. In a clean beaker, about 500 ml distilled water was brought to boil to evaporate dissolved gases. The water was allowed to cool down and 410ml was collected in a beaker. Exact volume, weight and initial temperature of the water were measured and recorded before filling the module.

Table salt from a local supermarket was used for making the saline solution. Distilled water was boiled to evaporate dissolved gases and cooled. The required amount water was poured into a beaker and the calculated amount of salt was added to it and dissolved. Exact volume, weight and initial temperature of the solution were measured and recorded before filling the module.

Powdered sugar from a local supermarket was used for making the sucrose solution in a similar manner as described above for the saline solution.

Internal pressure profiles were predicted in response to the recorded temperature profiles using the mathematical model developed by Ghai *et al.* (2011) for each of the three above aqueous solutions.

3. MATHEMATICAL MODELS

3.1. Model for Distilled Water

The internal pressure of plain distilled water could be predicted from the sum of pressures exerted by vapor and non-condensable gases. The vapor pressure of pure water as a function of temperature was calculated using the expression taken from the International Association for the Properties of Water and Steam (IAPWS) adopted in 1995.Pressures exerted by the non-condensable gases were predicted by the Ideal Gas Law.

3.2. Model for 5%Saline and 10% Sucrose Solutions

The mathematical model for predicting the internal pressure of saline and sucrose solutions was the same as that for distilled water, but expanded to include the application of Raoult's Law to the IAPWS' expression. A detailed description of how the model was developed can be found in Ghai *et al.* (2011).

4. RESULTS

Temperature profiles measured at the top and bottom of the module are shown in Figure 4, along with the retort temperature profile. These profiles reveal a measurable difference between top and bottom

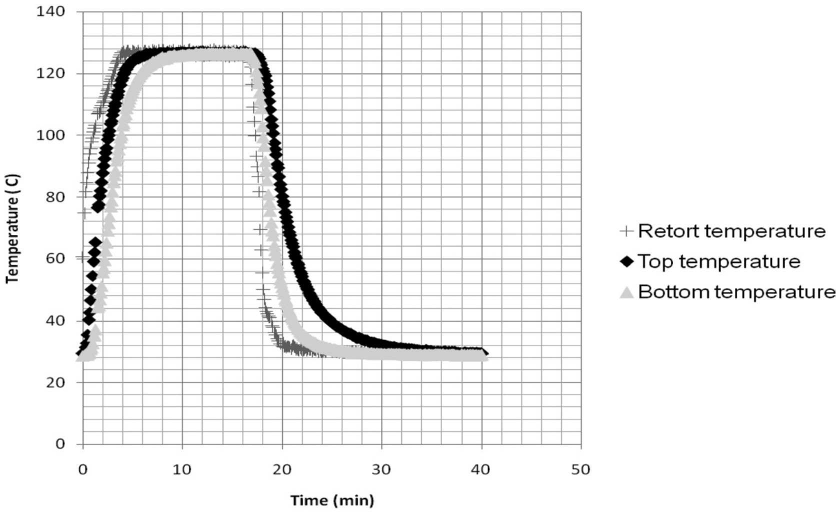

__Figure 4.__ Measured temperature profiles at top and bottom of pressure-tight module during retort process for distilled water by Paluri.

temperatures during come-up time. For example, at four minutes into the come-up time, the bottom temperature was 103°C, while the top temperature was 118°C. This difference results from natural convection currents in the liquid product generated by the lowering of density with higher temperatures at the boundary surface during come-up time, and is a phenomena well known in the field of thermal processing.

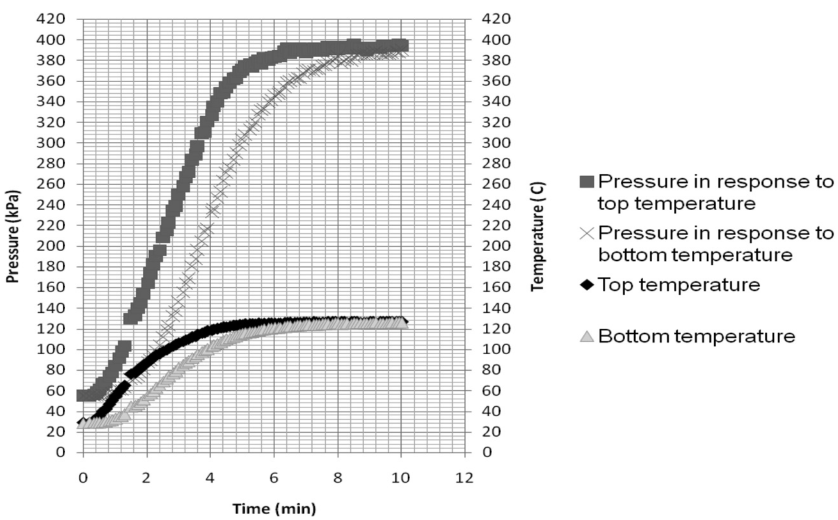

__Figure 5.__ Predicted pressure profiles in response to top and bottom temperature profiles along with top and bottom temperature profiles for distilled water by Paluri.

Model-predicted pressure profiles in response to the top and bottom temperature profiles, along with the temperature profiles, themselves, are shown in Figure 5. Note there is also a remarkable difference in predicted pressures during come-up time. At four minutes into the come-up time the predicted pressure in response to the bottom temperature was 232 kPa, while that in response

to the top temperature was 336 kPa. These differences are similar in order of magnitude to the differences between measured and predicted pressures reported by Ghai *et al.* (2011) shown in Figure 6. In that work, pressures were predicted in response to temperatures measured by a wireless data logger resting at the bottom of the module, while measured pressures were being generated in response to head space temperature at the top of the module. Measured pressure rose to 174 kPa at four minutes, while the predicted pressure rose to only 147 kPa. Differences in absolute values of pressure between those reported by Ghai *et al.* (2011) and those reported in this work resulted from differences in initial levels of vacuum (34.5 kPa vs. 50.8 kPa used in this study), as well as different retort operating conditions.

Predicted pressure profiles in response to top and bottom temperatures measured by Paluri in this work are compared with predicted and measured pressure profiles by Ghai *et al.* (2011) in Figure 7. Patterns of differences between values of predicted pressures from top and bottom temperatures measured by Paluri (Delta Paluri), and differences

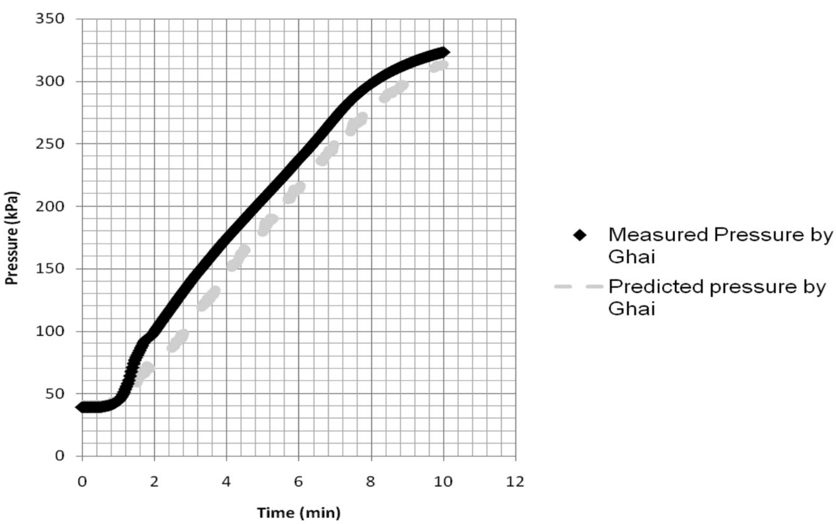

Figure 6. *Predicted and experimentally measured pressure profiles during come-up time for distilled water by Ghai et al. (2011).*

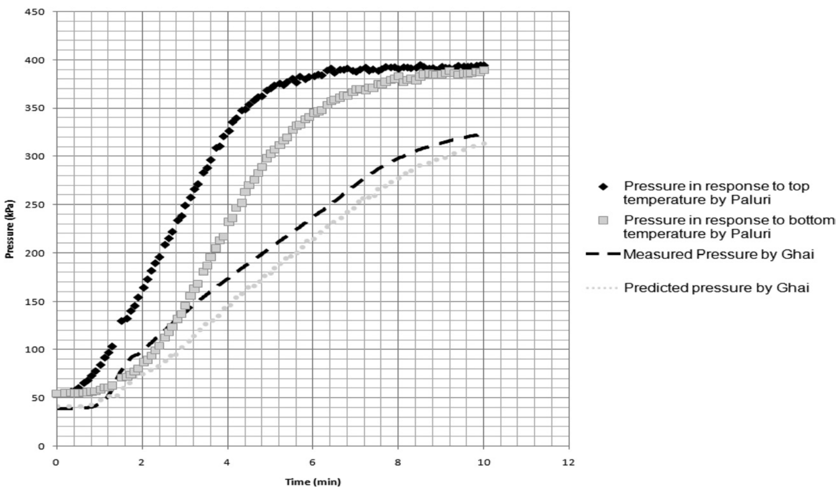

Figure 7. *Predicted pressure profiles from top and bottom temperatures by Paluri with predicted and measured pressure profiles by Ghai et al. (2011) for distilled water.*

between measured and predicted pressures by Ghai *et al.* (2011) (Delta Ghai) are shown in Figure 8. These delta pressure profiles show a similar trend in their patterns. Differences in actual values can again be attributed to the fact that retort operating and process conditions used by Ghai *et al.* (2011) differed from those used in this study. Results from experiments with saline solution (5%) and sucrose solution (10%) were similar to those of distilled water.

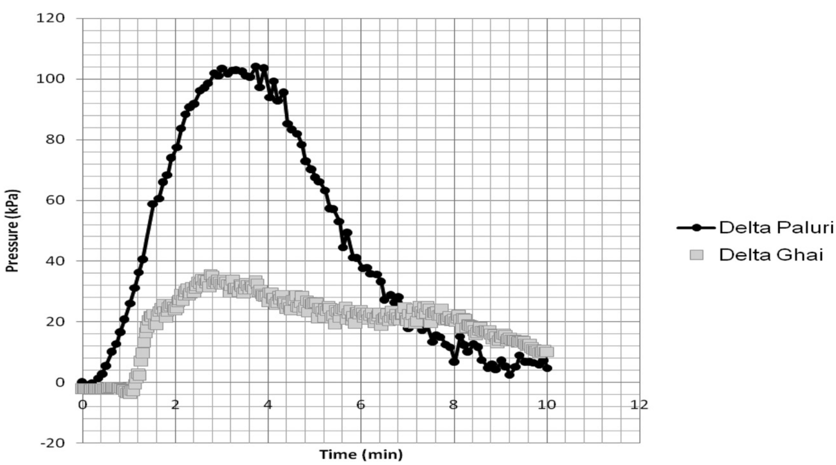

Figure 8. *Comparison of differences in pressure profiles predicted from top and bottom temperatures measured by Paluri (Delta Paluri) with differences between predicted and measured pressure profiles reported by Ghai et al. (2011) (Delta Ghai) for distilled water.*

5. CONCLUSIONS

Results from this work showed that patterns of differences between pressures predicted in response to top and bottom temperatures measured by Paluri were similar to those between measured and predicted pressures reported by Ghai *et al.* (2011). These findings would suggest

that the lack of agreement between measured and predicted pressures shown by Ghai *et al.* (2011) was likely due to the reason that the temperatures used to predict pressures were measured at the bottom of the module, while measured pressures were generated in response to headspace temperature at the top of the module.

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Table 5. Comparison of state-of-the-art matrix resins with VPSP/BMI copolymers.

Resin System	Core Temp. (DSC peak)	Char Yield, %
Epoxy (MY720)	235	30
C379: H795 = 14	285	53

8. Symbols. A list of symbols used and their meanings should be included.
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    Secondary Subhead: Principle of the Design Method

13. If further subordination is required, please limit to no more than one (*Third Subhead*).
14. Equations. Number equations with Arabic numbers enclosed in parentheses at the right-hand margin. Type superscripts and subscripts clearly above or below the baseline, or mark them with a caret. Be sure that all symbols, letters, and numbers are distinguishable (e.g., "oh" or zero, one or lowercase "el," "vee" or Greek nu).
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