Increasing Capacity by Designing a New Drying Process at a Manufacturing Plant

María del Mar Figueroa
Manufacturing Engineering
Carlos Pons Fontana, Ph.D.
Industrial Engineering Department
Polytechnic University of Puerto Rico

Abstract *— High oil price is one of the major factors for this twenty-first century global economic recession. Inevitably everyone's mindset has changed towards energy and the focus is towards finding renewable energy that result in satisfactory substitutes like solar energy has proven to be. For the past years, established manufacturers for solar panels have experienced a significant increase in the demand of these product or its raw materials, resulting this in a challenge for these manufacturers since they were simply not ready to supply the demand currently being requested. One of these solar panels manufacturers is an electronics plant located in Manatí, Puerto Rico, were only half of the solar panels products demand is being supply at a "sold out" position. Thus, this project uses a Design for Six Sigma approach to increase the capacity of the Manatí solar panels related production.*

Key Terms *— Capacity, Drying, Horizontal Vacuum Dryer, Solar Panels.*

PROBLEM STATEMENT

Over 100 countries are generating electricity by solar panels, which explains why this is the world's fastest-growing energy technology, increasing each year by an average of more than 20%. Due to this growing demand for renewable energy sources, the manufacturing of solar panels have advanced considerably in recent years and an electronics manufacturing plant in Manatí, Puerto Rico is not the exception. In fact, the Manatí plant demand has doubled due to their solar cell panels products, but capacity restrictions has made impossible for the plant to supply the requested demand to their customers.

Analysis made to increased plant's capacity have showed that major bottleneck is in the drying step due to the technologies that have been used, alternatives with very long cycle times. Thus, there is the need of a faster drying technology that increases the capacity of the plant to supply solar panels demand.

Research Description

Current drying technologies of the electronics manufacturing plant are the bottleneck of the production area since they are steady technologies where the drying time is predetermined by an overestimate of the drying time to assure dryness. Yet, even with these cycle time disadvantages anyone may have thought that instead of improving these long cycle times, an easier way to increase the plant's drying capacity is perhaps by adding more of these steady dryers, but the reality is that this is not possible since there is no available space at the plant not even for one more dryer.

An expansion of current technologies is not possible since these require a large real state plus business wise it is not the right thing to do since it means expanding on obsolete technologies with the longer cycle times in the market. Thus, the focus of this project is in studying the feasibility of developing a new, faster drying technology that increases heat transfer through mixing and that it fits in the same real state provided so that current drying processes at the Electronics plant can be replaced.

Research Objectives

The objective of this research project is to increase the electronics manufacturing plant capacity so that solar panels demands can be met. The design project will reduce drying cycle time by 50% with new, smaller drying equipment that will allow replacing one of the old dryers with two of the new ones but would not jeopardize products quality.

Research Contributions

Manatí's plant drying technologies are completely manual processes, requiring 100% dedicated resources to monitor the process, resulting this in a lot of wastes associated to time and resources needed. So, this new drying process would be a less labor intensive process since dryer operation will be control through PLC that would provide a good identification of powder dryness since product drying end point will be determined by drying curves provided by the PLC.

LITERATURE REVIEW

It is well known that during drying, excess water is extracted from a material, but perhaps what it may not be of common knowledge is that drying is one of the most important stages of technological processes nowadays [1]. Drying is in many cases the final production step before selling or packaging products because it improves the material technical properties and the possibility of a longer storage, being this exactly true for the drying processes held at the electronics manufacturing plant at Manatí, Puerto Rico.

Currently, the last steps of the electronics plant process are not only the main drying technologies of the plant, but these are obsolete when compared to most recent drying technologies since the material is not mixed at all while drying occurs.

It is a fact that the rate of drying is determined by the rate at which heat energy can be transferred to the water, driven by the temperature difference (ΔT) either in conduction, convection and/or radiation. However, as drying proceeds, dry material begins to occupy the surface layers and conduction must take place through these dry surface layers, which are poor heat conductors, so heat is transferred from the drying region progressively more slowly (see Figure 1). Actually, because of this movement pattern of moisture changes, the rate of mass transfer (removal of the water) is not as straightforward as heat transfer, turning it to be the limiting factor [2].

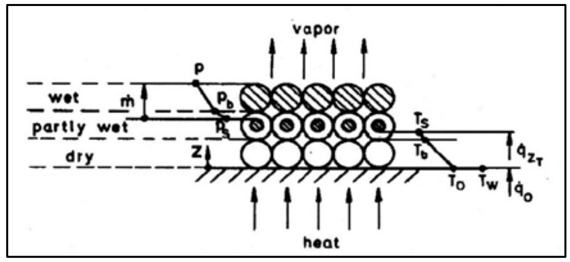

Figure 1
Heat and Mass Transfer Resistances in Contact Drying

All In drying, the water that is loosely held is removed most easily, so it would be expected then that the remaining water being bound more and more strongly, decreases the drying rate. As drying proceeds the moisture content falls and the access of water from the interior of the material to the surface affects the rate and decreases it. Thus, Figure 2 explains how in order to achieve uniform drying of the particulate material, the particle layers need to be agitated mechanically [3].

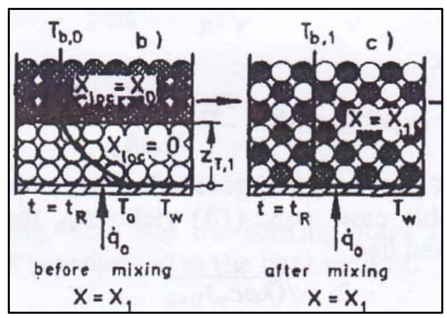

Figure 2
New Contact Drying Model

The rate of water removal will depend on the conditions of the air, the properties of the material and the mixing design provided by the dryer. Yet, although there are many types of batch, agitated vacuum dryers, they all operate under similar principles. Generally a jacketed dryer is loaded with wet material, the dryer is sealed to permit vacuum operation (25 in Hg) and the drying cycle begins when vacuum is established. Drying is done by indirect heat transfer from the dryer's jacket to the wet product. Drying under vacuum accelerates drying by decreasing the volatile specie's boiling point and increasing the temperature difference between the product and the jacket. Vapor is removed from the dryer by the vacuum system. Vapor typically flows from the dryer, through a filter and condenser upstream of a vacuum pump. During the drying cycle, the product is mixed to enhance heat transfer. Mixing is done by internal agitators (i.e. stirrers, scrapers, paddles), choppers or by the entire vessel rotating, depending on the specific dryer type. When the product is dry enough, vacuum is broken, and the product is allowed to flow out of the dryer by gravity, and often by assistance from the dryer's agitator [2].

Certainly, the electronics manufacturing plant's dryers work very differently than an agitated dryer. Thus, in the present research, the feasibility of using a mechanically mixer-dryer with vacuum to dry a fine powder at the Electronics site will be investigated by creating experimental drying curves which are the only adequate guide for drying design.

Nowadays when talking about design, the standard of excellence to follow is Six Sigma. This strategy has two best known tools which are DMADV and DMAIC, being DMAIC the most common of both since it is used for projects aiming to improve an existing business process. On the other hand, DMADV starts with a fresh start rather than one that has defects, so is more like a separate and emerging business-process management methodology related to the traditional Six Sigma.

DMADV, which is also known as Design for Six Sigma (DFSS), is designing to meet customer needs and process capability. This may sound rather complex, but in reality it is similar to the Six Sigma processes for continuous improvement. The fact of the matter is that DFSS provides a proactive and systematic method needed to build important customer requirements into all related aspects of the design development process [4]. Clearly, having these customer requirements merge so deep into every step of the methodology allows that the linking into full scale manufacturing activities in a sooner, smoother way.

METHODOLOGY

The five DMADV phases was the framework used for the execution of this research project since completion of each phase was the driver towards the achievement of project objectives.

First phase of the DMADV methodology is the Define phase. This stage was used to design the project goals in a way that there was consistency with the customer demands. So, for this, collecting the Voice of the Customer (VOC) was critical.

"Going to the Gemba", which is a Japanese phrase that means "go to the source of information", was the way of collecting the VOC for this project since it consisted in observing the way customers work without the artificiality of interviews and conference rooms. It is in the Gemba were we really saw who our customers were, what their real problems were and how the product was used by the customer. The VOC collected through "Going to the Gemba" expected to reduce uncertainty and gained insights that helped make better decisions since very commonly when we actually go out and talk to and observe customers, we oftentimes learn that the pre-conceived notions were wrong. So, with little uncertainly is how moving into the next phase of the DFSS methodology, Measure, was done.

Measure phase determined what was important to the key customers and established how to measure it, and for this the Quality Function Deployment (QFD) was used. This tool helped translate customer requirements into company requirements. Its structured approach is normally used for more complex situations that deal with multiple customer needs, etc., like the electronics' plant drying research project had. The use of this QFD approach during this early phase allowed a solid understanding of the key customer requirements, making easier to portray the total concept and consideration of all the aspects that were needed to meet the customer requirements.

Next stage of the project was the Analyze Phase and is where the real thinking happened. At this phase the best design was to be developed by creating high level designs of the alternatives, evaluating their design capability and identifying the key elements in the new development/designs. A good pilot unit allowed testing the capabilities of the product or process at the scale or load that it is to be operated, and included all the logistics required to run the final process. So, the optimal design was expected to be determined in the most assertive way. Then, throughout the Design phase, simulations were required since at this stage the design and plan to implement the optimal design was created. A sufficiently detailed description of the design was done so that the process owners could unambiguously understand and implement it for the phase of operation at hand and control the process design in routine operation.

Finally, at the Verify stage the design was implemented and tested, generating data to demonstrate conformance to CTQ's at required Sigma Level. In this way, the performance of the developed design was verified through pilot runs' making sure the design was maintained and proving it was mistake proof. Implementation of the Design Basis at the appropriate scale converted the Design Basis into a working process that then was handed it over to the process owner(s). Full control and operation in hands of final "owners" established that future improvements were to be managed through either another DMAIC or DMADV project; leaving the improvement life cycle back to stage one.

RESULTS

Customer needs were gathered by "Going to the Gemba", which meant spending 8 hours a day observing the electronics manufacturing plant drying processes in order to see and feel the drying bottleneck problem. Steps such as loading, process monitoring and unloading of the dryers were observed and clearly, the areas for room of improvements were seen. The drying technologies were literally trays dryers were x amount of material was charged into a tray and left for a very extended amount of time where a technician would come and check if it was dry, if not process would continue until drying was completed.

Once the noticeable disadvantages of the current drying technologies were understood, the next two months were spent looking into the other drying options available in the market. Clearly, when compared to the newer drying technologies, the drying bottleneck of the plant could be solved by changing into any of the newer drying technologies, but for that, the following requirements were to be proven:

- Increase solar panels production capacity
- Accommodate several product families
- Meet current specs

In fact, this customer feedback was used for the Measure phase to determine what was to be measure and how to measure, so that not only it was determined what was important to electronics business, operations and quality groups, but more importantly, their inputs could be actually translated into specific, measurable needs.

This customer wants conversion to measurable requirements was made through the comprehensive QFD model presented in Table 1.

Table 1
QFD Exercise for Project Y's Selection

Trade-Off Matrix (Roof):	Drying End Time Indicator	No Agglomeration	Particle Size within specs	Surface Area within specs	Solids within specs	Finish Product within specs	Yields	Minimal Heel	Minimal Carryover
	+								
		-							
		+							
	-		-	-					
			+						
		+			+				
							+		

Direction of Improvement:											
Improvement: Increase Drying Capacity		Technical Requirements									
9=strong correlation, 3=moderate correlation, 1=weak correlation	**Customer Importance (1-5)**	**List Technical Requirements**	Drying End Time Indicator	No Agglomeration	Particle Size within specs	Surface Area within specs	Solids within specs	Finish Product within specs	Yields	Minimal Heel	Minimal Carryover
List Customer Wants											
Shorter Cycle Time	5		9	3	3	3	9	3	0	0	0
Less Real State	5		0	0	0	0	0	0	0	0	0
Flexible Technology	5		0	9	9	9	9	9	3	0	0
Reliable Equipment	4		1	9	3	3	9	1	3	0	0
Self Emptying of Product	2		0	3	0	0	0	0	3	9	0
Reduce Labour hours	4		9	0	0	0	0	0	0	3	3
Better Containment of Dust	3		0	0	0	0	0	0	1	3	9
Reduce Energy Costs	2		9	0	0	0	0	0	0	0	0
Easy to Clean	3		0	0	0	0	0	0	0	9	9
How Important			103	102	72	72	**126**	64	36	66	66

Without a doubt the QFD resulted in the right vehicle for determining the variables to be measured, which resulted to be: solids percentage, cycle time, appearance and surface area (SA). So, immediately after identifying these critical project outputs, how these were going to be measured was determined using data collection format presented in Table 2.

Table 2
Data Collection Plan

WHAT to Measure			HOW to Measure				WHO is Measuring	Evaluate Performance
Measure	Type of Measure	Type of Data	Measurement Tool	Measurement Resolution	Sampling Scheme	Sampling Frequency	Who is collecting the data?	Performance Standard
Cycle Time	Y	Continuous	Clock	secs	Systematic	Every lot	Mfg	</= Current
Solids	Y	Continuous	Box Furnace	+/- 10°C	Systematic	Every lot	QC Technician	Per product specs
Appearance	Y	Discrete	Visual Inspection	N/A	Systematic	Every lot	QC Technician	Ok/Fail
Surface Area	Y	Continuous	Micromeritics TriStar 3000	+/-0.02 m^2/g	Systematic	Every lot	QC Technician	Per product specs

At this point, not only how the data was to be measured is known, but based on the obvious current technology disadvantage, which is being a steady drying process, a high-level representation of what the new process should be and how the processes for delivering it might look like were identified during the Analyze phase and represented in Figure 3 and Figure 4.

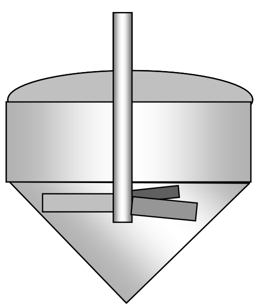

Figure 3
Concept A

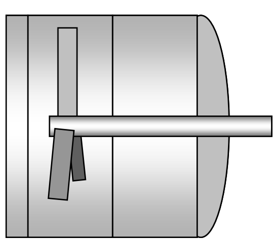

Figure 4
Concept B

Basically, both of these high level designs of the new drying process were proposed as two options for agitated drying equipment. Again, both selected with the clear objective of eliminating current drying processes drawback: no agitation during the drying process. Therefore, throughout the Design phase the concepts were to be proven if indeed were the much faster concept the customer needed and allowed meeting all the project Y's. However, how were these two new concepts were to be tested if no equipment was to be bought prior to proving all customer requirements were achievable?

After extensive thinking, it was decided that these new designs were to be studied throughout the use of a pilot unit. Yet, renting two pilot units was not a money wise option so in order to select one of the concept designs both of the suppliers site of each of the proposed equipments were visited. Trials done helped determined the option that had the highest potential to be moved into Manatí as a rented pilot unit: concept B, the horizontal dryer presented in Figure 5.

Figure 5
Horizontal Dryer Pilot Unit

Rented pilot unit arrived to Manatí on mid-year of 2010 and for six consecutive months, the equipment was tested to defined the "control knobs" that could allow meeting all the manufacturing plant needs. For this, a three level full factorial Design of Experiment (DOE) was determined to be run for the most complex product families, that is Family A.

Optimum settings for processes variables, such as, loading level, agitation and temperature controls were to be established. Yet, out of these three critical X's, loading level was the most critical since there was really no knob here. It was vital that for to make the new drying technology more marketable, a full loading, 70% of the equipment utilized, could be possible and that at this loading, all project Y's were met.

During the literature review of this research it was learned that to achieve full loading of the equipment, the way the material is added to the equipment is critical, and this could be either be done through a total batch process or fed batch process. Meaning total batch process when the total amount of a batch is fed to the dryer in one initial addition. On the other hand, the fed batch process consisted in periodical small additions of material to the dryer. Actually, it was the feeding of small portions every certain period of time, that allowed having always a "dry base" and consequently, avoiding the "liquid phase" of the drying cycle. Certainly, a knowledge that helped in the management of foaming that certain types of product families create during the drying, thus in how much the equipment loading percentage could be stretch up to the maximum as possible. So no doubt that the DOE study consisted in four variables: temperature, agitation, loading level and type of addition, fixed based on the surfactant (i.e. foaming) of the product family to be dried.

How did the DOE result (see Figure 6)? After seven runs for Family A, an optimum settings combination, that allowed that the dryer could be filled up to the maximum desired level and met all project Y's, was found: low temperature, low agitation and a fed batch approach.

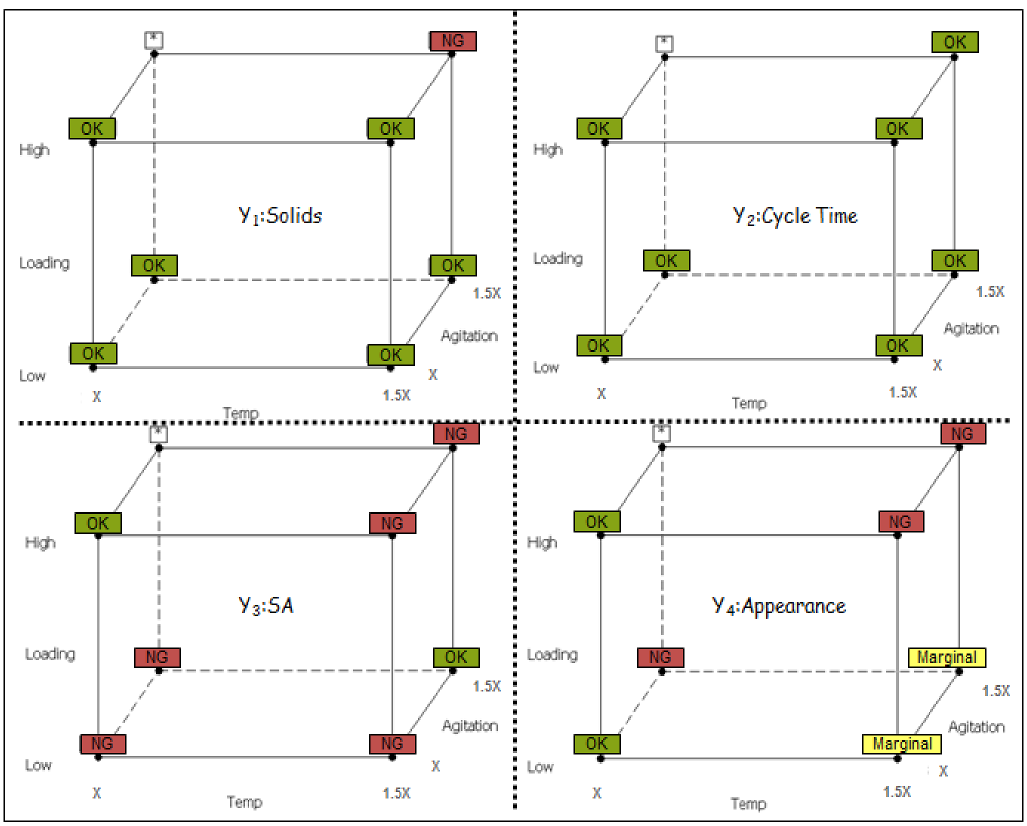

Figure 6
Design of Experiment Results

Full level DOEs were not needed for every product family since with the learning and results of Family A; execution of the experimental runs for the other product families (i.e. Family B and Family C) was significantly facilitated. Basically, once the type of addition to be used was defined, the low agitation knowledge was applied since it was learned through Family A experimentation that this also helped in filling the dryer up to the maximum level as possible and meeting appearance spec. So, this was the also the reason for not doing the high agitation and high temperature run in the DOE for Family A.

What about the temperature setting? This was the only knob missing for the other product families so trials were done at low and high temperature settings. Results of these plus the very original DOE variables are summarized in Table 3.

Table 3

DOE Summary

	X_1	X_2	X_3	X_4
Product Family	Temperature	Loading	Agitation	Batch Addition
A	Low	High	Low	Fed
B	High	High	Low	Full
C	Low	High	Low	Full

Finally, this simple table was the proved that a full-scale implementation was ready to be done, using all of the information gained during the earlier phases. Thereby, a new drying process was to be fully developed at the electronics plant and so, a capital project was approved to buy the rented pilot unit and two more horizontal dryers.

After 6 months in the implementation of these new equipments, the process was verified making confirmation runs, which is generally the most tangible manner to do this. Based on the seven verification runs, made on the full scale and shown in Figure 7, design was verified.

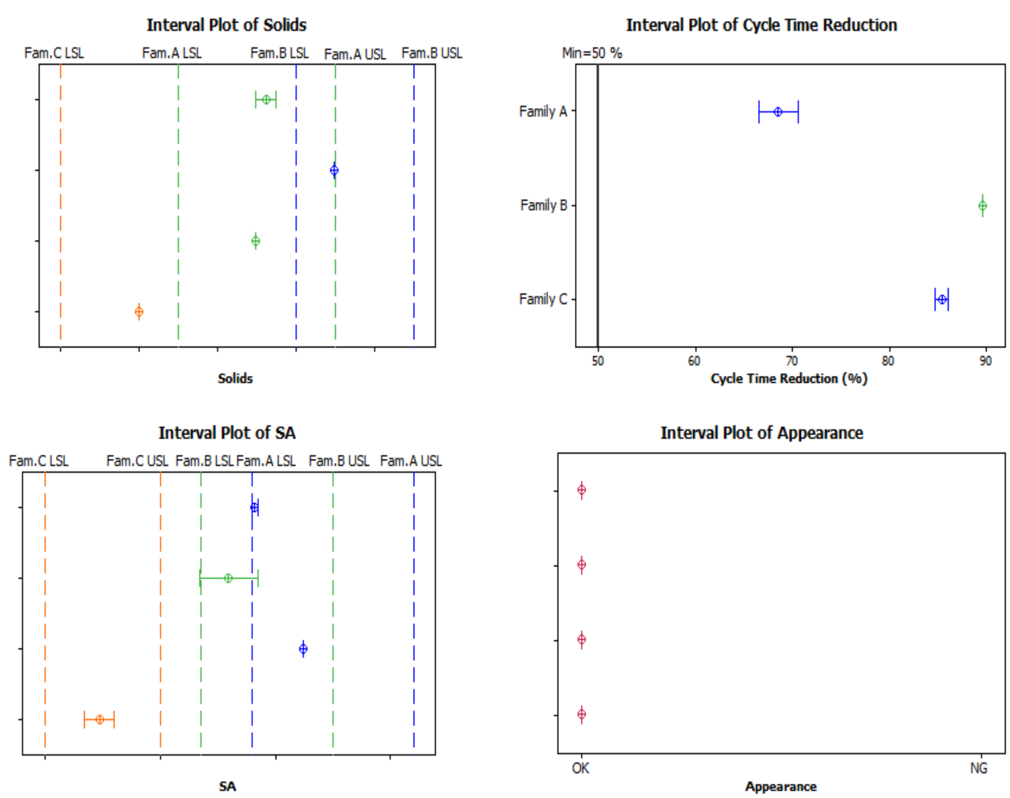

Figure 7
Design Verification

The three product families resulted within specs sustaining the cycle time improvements. An improvement that had all the supporting data to qualified the process up to finish product performance. Fortunately, finish product data strongly supported the new drying process demonstrating equal or better performance. So, a control plan was documented to serve as the official document whereby future changes were to be added or deleted at the same time electronics' plant users became experts with the new HVD drying technology.

A new drying technology that resulted better in cycle time performance and equivalent to lots made at the old dryers, quality wise. Data presented in Figure 8 proved that HVD was the right technology to move into.

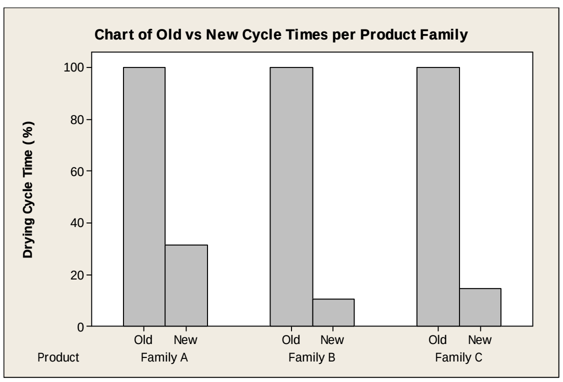

Figure 8
Cycle Time Improvement

CONCLUSIONS AND RECOMMENDATIONS

It was with this same data and one year of work throughout this Design For Six Sigma project, that five HVD's will occupy the same space two old dryers take, six grades showed equal or higher quality when dried at the HVD, 80% is the cycle times reduction and a PLC process allowed the elimination of trays and all the labor associated to this, providing a safer and more cost effective process.

The Horizontal Vacuum Drying has shown that it is the alternative drying technology that the electronics manufacturing plant needed since it reduced cycle time, without jeopardizing quality, in more than the 50% expected and guarantees a significant increase in solar panels capacity. The approval of this new drying equipment has changed the Manatí plant, but only for good.

However, solar panels production is just one of the many products the Manatí plant supplies to the world, some that are still being run with obsolete technologies like the old dryers. So, future projects will come and it is necessary to always benefit from what is a custom made design versus just settling for an optimization to the existed. It surely is more complex, yet results to be made are dramatically significant. It is so, that the achievement of increasing the plant solar panels production was a headline of the most viewed Puerto Rico newspapers, celebrating the new job opportunities that brings growth.

REFERENCES

[1] Kutovoy, V., L. Nikolaichuk, and V. Slyesov, "To the Theory of Vacuum Drying" *Drying 2004-Proceedings of the 14th International Drying Symposium,* Vol. A, August 2004, 266-271.

[2] Marsh, Schuyler, *Letter to Luis Solá, "Powder Drying Summary",* Ed. DuET Particle Technologies Station, Jan 2010, 42.

[3] Schündler, E.U., and N. Mollekopf, "Vacuum Contact Drying of Free Flowing Mechanically Agitated Particulate Material", *Chemical Engineering and Processing: Process Intensification*, 18.2, 1984, 93-111.

[4] DuPont, "Black Belt Training", *DuPont Headquarters,* Version 11, 2007.