Sustainable Improvements for Guatemalan Cardamom Spice Dryers

Project Description

A U.S. mechanical engineering (ME) student was in her sleeping bag in a cardamom spice drying facility in rural Guatemala when she was suddenly shaken awake. Her eyes blinked open to the owner of the dryer facility, A.C., beaming enthusiastically. A little startled, slightly drowsy, but smiling back, she glanced down at her watch face: 1 AM. A.C., barely noticing the time, exclaimed, "*¡Por fa, enséñanos a hacer las espirales!* [Please, teach us how to make the swirlers!]" His statement jolted the student awake more than any caffeinated drink ever could.

A.C. had been drying cardamom for 16 years and was well acquainted with the drying process. The previous day he was skeptical of the value of this student team's new technology: swirlers. When A.C. discovered that those swirlers had cut the drying time from 36 hours to 31 hours and firewood consumption by half a cubic meter, formalities were abandoned, and he was not going to wait until the sun rose to share his excitement. Furthermore, the dryer's temperature remained more consistent, producing higher quality cardamom which would garner a higher sales price. Calculations revealed that the swirlers reduced total processing costs by 15%.

A university student teaches A.C. to make swirlers at 1 AM

A.C. takes over as instructor

Cardamom is an economic lifeline for the country. Guatemala is the world's leading exporter of this expensive, highly sought-after spice used around the world for both sweet and savory dishes. Guatemala accounts for 80% of the global cardamom trade, producing approximately 30,000 metric tons of cardamom each year valued at an impressive $580M. Unlike many export commodities which are predominately in the hands of large multinational corporations, 300,000 indigenous farmers produce almost 70% of Guatemala's cardamom exports on small plots of 4 hectares or less. Unfortunately, however, most of the cardamom is dried in inefficient wood-burning dryers. The 720,000 m^3 of firewood and 27 million liters of diesel used to process cardamom each year exacerbates the immediate and long-term crises caused by Guatemalan deforestation and global climate change. Improving cardamom dryer efficiency while reducing drying costs brings both immediate and long-term ecological and economic benefits.

The endeavor to improve cardamom dryer efficiency was initiated by the Guatemalan spice farmers and dryer operators and was further advanced by a Guatemalan agricultural NGO with whom they had an existing relationship. The NGO had been facilitating the formation of smallholder cooperatives to empower those farmers to dry their own cardamom, eliminate an intermediary, and therefore increase their personal income. It was in this context that the farmers and dryer operators had expressed interest in improving dryer efficiency. The NGO initially planned to completely replace the traditional dryers with efficient modern machinery. However, with 6,000 dryers in Guatemala and a price tag of $12,000 per dryer, the NGO decided to concurrently investigate small-scale, low-cost adaptations for existing dryers. They approached a humanitarian engineering NGO for assistance in accomplishing this goal which in turn spurred a connection with the U.S. mechanical engineering students.

This was a unique challenge. Every design of a school, bridge, or water distribution system has engineering challenges to overcome, but there is substantial experience in the design and construction of these projects by faculty, professional mentors, and in-country representatives. These projects have both a destination and a road map, and students can be guided along a clearly defined process. This cardamom project, however, had no road map. This group of highly motivated students took on the challenge of creating that roadmap.

First Student Trip to Guatemala

The team's first step was to engage with primary stakeholders and gain an understanding of the drying process and every part of the machinery. They traveled to Guatemala in March 2018 with their faculty advisor to meet with cardamom farmers, dryer operators, and representatives of the NGO. The team also gathered detailed measurements from three dryers.

The basic components of most dryers are the following: a firebox where wood is burned, a small diesel engine driving a fan to push air through a heat exchanger, and a 3 meter diameter bin with a perforated floor that allows the heated air to flow through the cardamom pods. With guidance from faculty and a P.E. mentor, the students learned that 46% of the heat input to the system was lost in the heat exchanger and firebox and 24% was lost at the dryer surfaces, resulting in only 30% of the input heat actually being utilized to dry the cardamom. It was clear that the greatest potential for improving efficiency resided in the heat exchanger, so they brainstormed and analyzed several heat exchanger modifications.

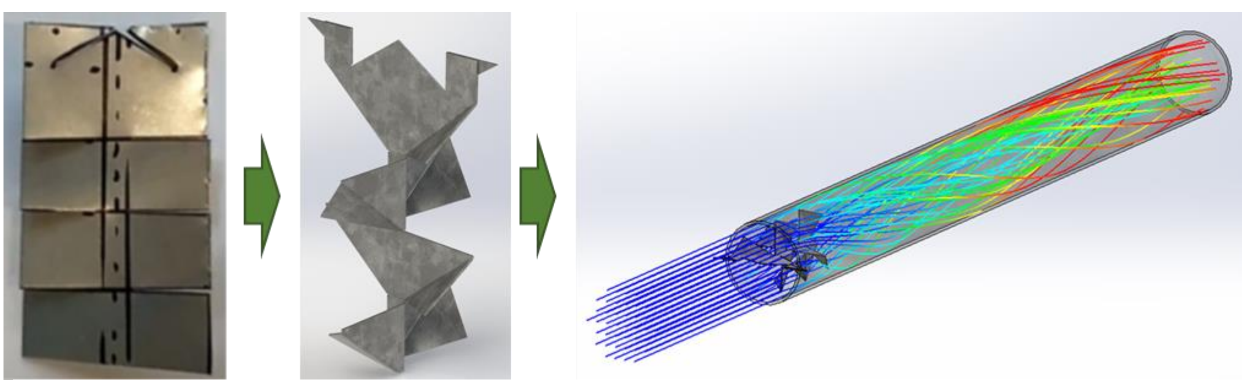
The team also saw firsthand in Guatemala how previous "improved" cardamom dryer prototypes were sitting in corners unused and collecting dust. Why? The designers had solicited minimal, if any, input from the farmers and dryer operators and therefore were not cognizant of the premium placed on time efficiency. Those dryers were ecologically beneficial, but they were not user friendly because the dying sessions took even longer than the traditional 36 hours. Time is of the essence, as there is a tight 12-hour window from the time cardamom is harvested and must be dried before it begins to rot. Time efficiency is not just a preference; it is a necessity. The disused "improved" dryers served as a vivid illustration of the value of stakeholder input, and the team knew that any solution would have to be time efficient.

"Swirler": A Promising Idea

The team had an excellent group of advisors ranging from faculty, professional engineer mentors, and a diverse international group of stakeholders. However, this project took everyone into uncharted territory.

The team embarked on a journey that involved substantial trial and error. Failed idea after failed idea in the engineering design process led to some team discouragement until something very unexpected happened in Fall 2018. D.B., a retired Guatemalan cardamom dryer operator, discovered the team's cardamom project challenge from the university's website while conducting personal research on ways to improve the drying process and reduce wood consumption. He initiated contact with the team which in turn revived morale. D.B.'s contribution was priceless as he shared his knowledge and experience with the students and volunteered to collect on-the-ground data while the students worked thousands of miles away.

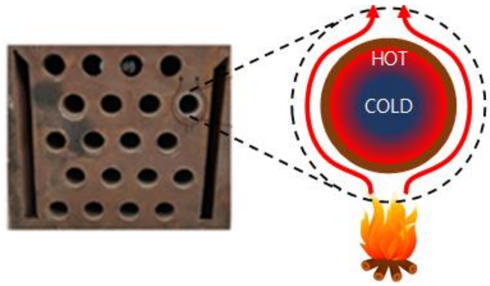
Researching, designing, and vetting various options was a significant growth process for the students. By early 2019, the students discovered one promising idea: an existing heat exchanger technology known as twisted tape. However, the manufacturing process for twisted tape was complicated and not a viable solution for this context. The students ultimately developed what they called the "swirler" to sit in the heat exchanger tubes– a solution which met the criteria for what is commonly referred to as appropriate technology. A technological solution which is "appropriate" is one which is low-maintenance, energy-efficient, environmentally sound, and facilitates autonomy. In other words, it can be locally funded, implemented, and propagated.



Swirlers cut and bent from sheet metal can easily be installed into the heat exchanger tubes increasing turbulence and promoting better, more efficient heat transfer

Exactly how does the swirler create such a significant impact? A cardamom dryer's heating process begins as the firebox heats the heat exchanger tubes, also heating up the air inside the tubes. When the air flow in the tubes is laminar, heating occurs non-uniformly and inefficiently as air near the walls of the tubes gets hot but air in the middle remains cooler. However, when swirlers are placed in the tubes, the air flowing through becomes more turbulent and the heating is more uniform, resulting in warmer air reaching the moist cardamom pods.

The team's design challenge became the following: optimize the shape of the swirler for maximum heat while ensuring that fabrication and installation would be a straightforward, non-complex process which was economically viable for the average cooperative member or dryer operator. The students used computational fluid dynamics analysis software to understand the flow path and predict the effectiveness of swirlers with fins of varying lengths and angles. To verify those predictions, they developed a testing apparatus that scaled the 36-pipe heat exchanger down to a single pipe with a heat source, fan, and thermocouples. Design of experiment principles were applied to minimize the number of prototypes and tests.



Non uniform, inefficient heating in a heat exchanger tube without swirlers

Second Round of In-Country Testing

The objective of the second trip to Guatemala was to pilot test the optimized swirlers in dryers during actual cardamom drying cycles. The students were mindful of the amount of trust the farmers and dryer operators were extending by allowing them to alter a process upon which their incomes depended. Three facilities had granted them permission to install and test the optimized swirlers. Referring back to A.C. who was mentioned in the very first paragraph, his facility was one of the three. When the drying cycle completed five hours ahead of schedule, he wanted to *immediately* start making swirlers for his other cardamom dryer and he needed instructions– at 1 AM! When all tests were completed, data revealed that the swirlers decreased firewood consumption by 20% and drying time by 14%. The reduced drying time also translated into reduced labor costs and diesel consumption. The reduced wood, diesel, and labor costs amounted to a 15% reduction in total processing costs.

Installing a dryer with swirlers costs less than $2. The sheet metal and two hand tools needed are available in a typical rural village hardware store. The fabrication process is well within the capabilities of the local population when provided with basic training. As the swirlers could be funded, fabricated, and installed without a dollar of outside assistance, the solution could be widely and rapidly disseminated. Replication could occur by multiplication, not just addition– as is the case when solutions require outside funding, equipment, or expertise.

Upon returning to the U.S., the student team immediately began collaborating with the Guatemalan agricultural NGO to develop open-source training materials. Such materials would need to demonstrate the immediate economic, ecological, and timesaving benefits of swirlers, illustrate how swirlers function, and provide clear instructions for fabricating and installing them. They did so by creating videos and other multilingual materials which are now being used by the NGO to equip end users to make and install swirlers in their own dryers. This year the NGO is actively engaged in both the training and fabrication process to iron out any kinks that may exist, with a goal of reaching 60 dryer facilities by the end of 2021. Provided that COVID-19 vaccinations become readily available, the NGO will significantly scale up the pace next year, potentially training more trainers, with the goal of training operators of all 6,000 dryers in Guatemala as quickly as possible.

If swirlers were installed in all 6,000 dryers, an estimated 144,000 m^3 of wood (1,500 hectares of forest) and 3.8 million liters of diesel fuel would be saved each year, resulting in an annual reduction of 112 million kilograms of CO_2e.

While the swirler solution is quite simple, the process was arduous. The students had to grapple with the complexities of the world's pressing issues, including the push and pull of economy and ecology. They grew in cross-cultural competency while interacting with university educated Spanish-speaking Guatemalans, Q'eqchi' speaking rural small-holder farmers, country-level directors of large international NGOs, and more. They utilized their classroom learning to develop a scalable solution which directly impacts the quality of life in rural Guatemalan communities. They learned that local knowledge and experience is priceless– without which it would have been near impossible to arrive at a solution that made the cardamom process both more ecologically sustainable and economically beneficial. The team never would have anticipated that tin snips, pliers, and two square feet of sheet metal would create more profitable farming, fight climate change, and connect such economically, linguistically, and culturally diverse communities.

Collaboration of Faculty, Students, and Licensed Professional Engineers

The student team became involved in this initiative when two mechanical engineering (ME) students approached two civil engineering (CE) faculty P.E.'s who had been partnering with an engineering NGO on development projects in Guatemala since 2006. The students inquired if there were any Guatemalan projects in need of mechanical engineering support. The timing of this inquiry coincided with the request for assistance from the Guatemalan agricultural NGO. The first step of collaboration was connecting with the Guatemalan agricultural NGO and subsequently to a broader network of NGOs and professionals who could mentor them throughout the project.

The students promptly contacted a mechanical P.E. who had conducted an energy study on typical Guatemalan cardamom dryers. He explained the system and guided them through a process of discovery to determine that the heat exchanger should be the first component to investigate.

Guatemalan P.E.'s were also key collaborators. A licensed civil engineer handled all in-country project coordination. A licensed agricultural engineer provided insights on climate change and the Guatemalan agriculture industry. He explained the economic impact of the high costs of cardamom drying, and how improving efficiency would improve the industry's long-term viability, enhance livelihoods, and even reduce economic immigration pressures.

Student collaboration began as a team of two, but significant expansion occurred as more students learned about the opportunity to apply what they were learning in the classroom to solve a real-world problem. The full team totaled 21 members who were studying mechanical engineering and industrial engineering.

The project also attracted multiple ME and CE faculty who provided professional mentorship during the various phases of the project. An ME faculty member and an industrial engineering faculty member aided the students in defining the project scope and breaking the relatively large and somewhat intimidating problem into smaller manageable segments. Together, they determined the important system variables and local manufacturing capabilities to investigate. A second ME faculty member joined the team to explain concepts of heat transfer and fluid dynamics to students who had not yet taken those courses. He provided an overview of heat exchangers and helped the team identify various approaches for improving them.

The students received invaluable support from a CE faculty member and P.E. who had lived in Guatemala eight years and had worked on engineering projects in Guatemala for over 20 years. He equipped the team with cross-cultural training and provided insights on local manufacturing capacities and material availability, all while reiterating the principles of appropriate technology. He then traveled with the students, assisting in logistics, translation, and general guidance.

When the students returned from the first trip and began optimizing the swirler design, a third ME faculty member provided guidance in the design of a unique experimental setup to evaluate the performance of numerous swirler variables such as swirler length and fin width. The students experienced firsthand the complications involved in obtaining and applying specific metrics needed to evaluate and improve their design. The ME faculty member helped them simplify their experimental procedure to allow for more focused testing with clearer metrics to define what would constitute a successful prototype. They applied fractional factorial design strategies such as Taguchi's method to reduce the number of optimization experiments from 54 to 9 and wrote MATLAB scripts to collect the required experimental data.

Students testing swirlers on an experimental testbed

A fourth ME faculty member traveled with the students on the second trip to Guatemala when the optimized prototype was field tested. He assisted the students in the process of in-field testing, especially in the areas of troubleshooting, data collection, and data analysis.

Following the successful results of the field test, the two CE faculty advisors subsidized the students' trip to a national humanitarian engineering conference to publicize the project results and invite others to join the cardamom dryer initiative to investigate additional improvements.

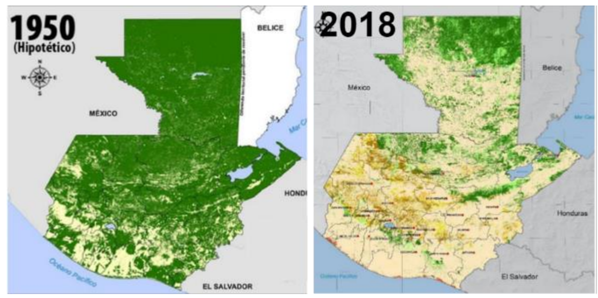
Dissemination of this new technology required training resources on how to fabricate and install swirlers. The students worked with another faculty member specializing in technical communication, instructional design, and user experience to create instructional videos and printed materials to ensure that the presentation of information was culturally appropriate and accessible to the average farmer of any educational level.

A fifth ME faculty member and P.E. worked with the team to estimate the total CO_2e reduction if swirlers were installed in all cardamom dryers in Guatemala.

Finally, the baton was passed. The two students who led this project recently graduated and helped organize and are currently mentoring three multidisciplinary teams to investigate five identified cardamom dryer improvements. These teams are composed of university students, faculty members, two P.E.'s, and other professionals from across the U.S. in the fields of biology, agricultural engineering, microbiology, and mechanical engineering. It is anticipated that all this work will also further increase dryer efficiency.

Protection of Health, Safety, and Welfare of the Public

The goal of any community development project, regardless of the discipline, is to improve general welfare while empowering local communities to meet their own needs and accomplish their own goals in an environmentally responsible manner.



Deforestation in Guatemala, 1950 - 2018

The impact of deforestation in Guatemala since 1950 has been devastating, causing natural disasters and economic hardship. The Intergovernmental Panel on Climate Change estimates that 20% of all global carbon emissions are generated by deforestation. Of the 112 million kilograms of CO_2e saved annually by this project, 101 million kilograms is due to the savings in firewood alone. Besides the long-term impacts of mitigating climate change, there are immediate positive impacts associated with the reduction of firewood consumption in the cardamom drying process.

Disaster Mitigation

Many areas of Guatemala are vulnerable to landslides due to terrain and meteorology. When trees are removed, this is exacerbated because topsoil can readily shift under intense rain or earthquakes, both common occurrences in Guatemala. Landslides destroy homes, businesses, crops, livestock, and human lives, and this happens time and again. The most recent example is Hurricane Eta which struck Guatemala in November 2020. Landslides were responsible for the majority of deaths. Reducing deforestation increases physical safety and reduces economic vulnerabilities especially for people with no insurance policies.

Economic Security

The drastic reduction in trees has correspondingly driven up the cost of wood. While city dwellers primarily use gas stoves and most rural households at least have more efficient, enclosed woodburning stoves, 87% of rural Guatemalan households still rely on wood for cooking. Households either must spend more for firewood or spend priceless hours walking further and further to collect enough firewood, if there is any. One town the team visited in the cardamom-growing region is now forced to purchase wood from other regions at a very steep price. While it is unknown how many towns face this predicament, that number will only continue to increase. Change is needed on many fronts, but the bottom line is that reducing deforestation improves the economic stability of rural families and communities.

Reducing wood consumption also directly improves the livelihoods of the cardamom producers and their families. The one-time $2 investment to install swirlers reduces drying costs by 15% which equates to a total of $1,100 in savings per dryer per year. When dryers are owned by cooperatives of smallholder farmers, this savings will be distributed between all families. Privately owned dryers with swirlers will gain a competitive edge by charging less per batch and also saving farmers money which will motivate other dryer owners to follow suit. Increased economic security also reduces poverty-driven emigration, keeping families together and creating stronger communities.

Multidiscipline and Allied Profession Participation

Long-term success in development projects simply does not occur without thorough stakeholder engagement. While the technical solution to increase cardamom dryer efficiency came from the field of mechanical engineering, a host of additional collaborators ensured that the mechanical solution was economically feasible and contextually appropriate, and that the quality of the end product of dried cardamom was not negatively altered.

Cardamom Farmers and Dryer Cooperatives

Of utmost importance in this collaboration were the farmers and dryer operators themselves. Learning from previous unsuccessful attempts by others, the students solicited input from the farmers, especially those in cooperatives who co-owned their own dryers. Members of cardamom dryer cooperatives provided the students with valuable information from a business and scheduling perspective. They discussed the strengths and drawbacks of existing dryers, explained the drying rotation schedules, and provided specifics about quantity of wood used, wood cost per drying session, and drying times. D.B., the retired Guatemalan cardamom dryer operator who stumbled across the team's website, contributed significantly to the entire project's initiative by explaining improvements he had already researched, proposing other improvements to investigate, and critiquing the team's design.

Guatemalan Agricultural Engineers

Active engagement with agricultural engineers from the Guatemalan agricultural NGO enabled the team to understand quality control and quality criteria for dried cardamom, as any improvements to dryer efficiency must also yield a product with equal or higher market value. A Guatemalan agricultural engineer educated the students on how the cooperatives are formed and operate, served as a liaison between the students and the cooperatives, and initiated the in-country swirler testing program which began with the team's second trip and continued after the team's departure.

Guatemalan Cardamom Dryer Fabricators

Upon acquiring an understanding of the relevant concerns from farmers, cooperative members, and agricultural engineers, the team next solicited technical expertise from Guatemalan cardamom dryer fabricators. These fabricators were well versed in local tools, equipment, and materials and understood what would be financially and technically feasible to the average farmer. The students shared their prototype and received valuable feedback on design and fabrication.

Students, faculty, mechanical and agricultural engineers, and fabricators from the U.S. and Guatemala discuss swirler fabrication

Mechanical Engineers

The team solicited help from two mechanical engineers employed at two large U.S. manufacturers to complement the mentoring by their faculty. The team also benefited greatly from the expertise of an American mechanical engineer who has lived and worked in Guatemala for over 15 years. He added his perspective on Guatemalan materials and local manufacturing capabilities and served as an additional liaison between the students, cooperatives, and in-country swirler testing team members.

Guatemalan Agronomists and Agroforesters

Following the second trip during which the optimized swirlers were field-tested, the in-country testing program was continued by six Guatemalans specializing in agronomy and agroforestry. This phase of data collection and analysis required collaborating in three languages: Spanish, English, and Q'eqchi'.

Guatemalan Agricultural NGO Executive Leadership

After verifying the swirlers' success, the students presented their results to the Guatemalan agricultural NGO's executive leadership. During that meeting, the executive staff also unveiled their ten-year initiative to improve agricultural processes in Guatemala which included the implementation of a brand new, yet-to-be-designed, cardamom dryer to completely replace the existing 6,000 cardamom dryers. However, the Guatemalan executive director was shocked when he realized the impact of this simple, inexpensive solution, saying, **"We may need to rethink our ten-year plan."** Since then, they have shifted their emphasis to include development of additional incremental improvements for existing dryers.

Guatemalan Swirler Technicians and Educators

To develop the training resources on how to fabricate and install swirlers, the students not only worked with a faculty member but also the stakeholders receiving and delivering the training. The Guatemalan agricultural NGO assembled a team of technicians who is utilizing these materials to train dryer manufacturers, dryer operators, and farmers across Guatemala.

Knowledge and Skills Gained

The students were stretched in every step of this project, and it has prepared them to address complex challenges in their professional engineering careers.

Mentorship Plus Self-Learning

The students exercised personal initiative in seeking out mentorship from experienced engineers in various disciplines, without which the project would not have been successful. However, they also realized they cannot expect to be spoon-fed everything. The bulk of the team were underclassmen at the project's onset and had not been exposed to many of the requisite topics such as fluid mechanics, heat transfer, or computational fluid dynamics (CFD). While a professor provided overviews of these topics, the students had to press in and learn independently at an accelerated pace.

Project Management, Team Dynamics and Cross-cultural Communication

The team had to define the project scope and develop a project schedule using Gantt charts to stay on track. Beyond planning logistics, they learned to motivate and encourage each other during the frustrating iteration process of rejected ideas. They gained experience in coordinating a large cross-cultural and multilingual network of people residing in two countries.

The Circuitous Nature of the Design Process

The team explored many potential solutions such as deforming parts of the heat exchanger with a hammer, drying the cardamom in the sun or using desiccants, switching the fuel to bagasse or propane, and designing a system that utilizes liquid heat transfer. Significant time was spent brainstorming and vetting numerous ideas only to discover they would not work or were not practical.

Failure: Part of the Learning Process

These rejected solutions each had their drawbacks such as cost, complexity, availability of resources, and/or manufacturing involved. The students gained a realistic view of the often tiring and frustrating engineering design process. As tedious as this process can be, they realized that lessons learned from the previous failure are valuable for the next attempt.

Process of Design Optimization

Once the swirler was selected as the preferred solution, the students gained experience in designing an efficient testing program, collecting and analyzing data, and applying those findings to arrive at an optimized swirler design.

Engineering's Impact on Public Health, Safety, and Welfare

This journey brought to life the tangible impact engineers can have, as their simple design directly increases take home pay for local farmers and cardamom dryers. News coverage of Hurricane Eta in Guatemala was a vivid illustration of why reducing wood consumption is a matter of urgency. Their work will result in more trees remaining in the ground, preventing landslides and protecting homes, businesses, crops, livestock, and human lives. They were able to see the tangible impact on global climate change by calculating the estimated annual reduction in CO_2e.

Engineering to Empower, Not to Impress

The students learned that often a simpler, less impressive solution may be the superior option which empowers the end user. The team considered numerous design concepts, some of which were fairly complex and visually impressive. The final product, however, was a simple inexpensive bent piece of sheet metal. The simplicity of the design is empowering because the cardamom farmers and dryer operators can fund, fabricate, and install them. The power is in their hands to reduce resource consumption and increase profits, and they are not at the mercy of foreign benevolence to do so.

It's Not What Happens While We're There, It's What Continues Once We're Gone

Once A.C., the dryer operator, learned how to build swirlers from the student in the 1 AM training session, he was eager to pass on this new knowledge to his fellow technicians. Developing an effective design was gratifying for the team but developing a solution which can be replicated without continuous foreign involvement is even better. It empowers the beneficiaries to become the protagonists, passing on that same feeling of gratification to them. Give a man some swirlers, and he'll save a few trees. Teach him to make swirlers, and he'll teach others and save forests.