APPLIED R&D ON ***T-LUD TECHNOLOGY*** FOR CHARBRIQUETTE PRODUCTION IN CAMBODIA

PART 2-3

DEVELOPMENT OF 2 CHARRING-DRYING MODULES USING T-LUD TECHNOLOGY

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Acknowledgements

GERES Cambodia is grateful to Paul S. Anderson for sharing T-LUD stove technology, able to address and respond some of the energy needs in Southern countries. During his assignment in Cambodia in 2006, Mr. Anderson established the preconditions for all later achievements in the region.

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អង្គការដើម្បីភាពញញឹមនៃកុមារ
Pour un Sourire d'Enfant
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Abstract

GERES has been working on alternative solid biomass fuels since 2005, starting from Cambodia.

In partnership with the French association "Pour un Sourire d'Enfant" (PSE), GERES launched a project (2007-2010) whose main objectives were: **(i)** to implement a production plant processing renewable biomass residues into charcoal briquettes; **(ii)** to create job opportunities for people subsisting on waste-picking in Phnom Penh dumpsite.

GERES not only coordinated the project but brought technical expertise to develop a carbonisation equipment and briquetting process that could be appropriate to the urban context.

Since the drying process is an important determinant of the quality of charbriquettes, it appeared to be a good idea to use the heat generated by an adaptation of Paul S. Anderson's "T-LUD" stove technology[1].

The following technical report focuses on the development of pilot innovative drying equipment "recycling" the heat generated during carbonisation. It aims at drying the fresh raw material before being carbonized while, in the meantime, occurs carbonization of previously dried material. It was named "charring-drying module" (C-D module).

The report summarizes the R&D work conducted in Phnom Penh during the project, work that has been constrained by the availability of limited means, time and resources and that was aimed, additionally, at exploring the possibility of replicating the equipment in other contexts.

Even if this project was a great opportunity to conduct "applied R&D" mostly on carbonization and drying, the main objective was to implement within two years a viable production plant while creating jobs. No need to say it was ambitious. The need for volumes of charbriquettes in order to get substantial incomes for the workers has always been a higher priority than R&D work.

Author

Aurélien HERAIL has worked as Project manager for biomass energy and alternative fuel production for GERES in Cambodia and Mali. For four years he has managed SGFE charbriquette project in Phnom Penh, dealing with a broad range of activities from fundraising to implementation/operation stage. He has led related R&D work, partially depicted in this report. His expertise includes biomass carbonization and combustion, alternative fuel production, stove efficiency, technical evaluation and project management.

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[1] Detailed illustration thereof can be found in GERES report "*Applied R&D on T-LUD Technology for charbriquette production in Cambodia – Part1-3: Introducing T-LUD stoves for use in charbriquette production plants".*

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1. INTRODUCTION

The charbriquette production process is quite simple, but requires several crucial transformations in addition to briquetting:

1. Drying the raw material ("fresh" bulk biomass)
2. Charring the dried bulk biomass (the quality of charred material has a large impact on the quality of charbriquettes)
3. Drying the finished charbriquettes (this process directly impacts the energy content of the charbriquettes)

The great advantage of T-LUD technology in this process is that it produces high-quality char **from bulk biomass** while emitting a constant flame for the whole duration of the carbonization process. This presents a double advantage: not only **(i)** it releases very small amounts of harmful gases such as CO and CH4 during carbonization (and therefore reduces environmental/health impact), but also **(ii)** improves energy efficiency as the heat generated through the carbonisation process can be used for other purposes. Among them, one of the easiest and most rational uses is for the drying process.

Thus, the main objective was to use T-LUD technology, and specifically the recently developed *T-LUD pyrolysers*[2], in order to respond to the energetic needs of the charbriquette production. In order to accomplish this goal, two pieces of equipment were developed:

- ➲ **A charring-drying module** to undertake transformations 1 and 2
- ➲ **A charbriquette dryer** to undertake transformation 3

This report focusses on innovative charring-drying pilot equipment that was developed within the project implemented by GERES and PSE in Cambodia. Aim of the report is to publicize technical work and results.

By the end of the project, the enterprise *Sustainable Green Fuel Enterprise (SGFE)* was founded. SGFE produces and commercializes sustainable charbriquettes. The flowchart below gives an overview of the production process implemented at SGFE and identifies production steps using T-LUD pyrolysers.

2. FLOWCHART OF CHARBRIQUETTE PRODUCTION PROCESS IN SGFE

See next page.

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[2] Detailed illustration thereof can be found in GERES report "*Applied R&D on T-LUD Technology for charbriquette production in Cambodia – Part1-3: Introducing T-LUD stoves for use in charbriquette production plants".*

Charbriquette production process in SGFE

1/ Raw material collection

2/ DRYING, using heat produced in Step 3.

3/ CHARRING in T-LUD

CHARRING-DRYING module

4/ RAW CHAR

5/ CRUSHING

6/ MIXING
(char powder+binder+water)

7/ EXTRUDING

8/ DRYING: to reduce moisture content from 35% to 8-10%

Char briquettes DRYER

9/ DISTRIBUTION

END USE

3. CHARRING-DRYING MODULE

3.1 INTRODUCTION

Initially, targeted production capacity of the whole plant was set to 550kg of charbriquettes per day.

One objective of the project is to process coconut husk and shell as main raw material since it is abundant and husk is often dumped in Phnom Penh streets. However the technical challenge is how to reduce moisture content of the husk while ensuring a semi-industrial production capacity, especially during the rainy season?

Strategy was first to develop a prototype of innovative equipment (i.e charring-drying module) able to dry coconut husk while it produces char. Then, duplications of such validated equipment would enable to reach targeted capacity.

However, based on preliminary calculations, and due to time constraint of the overall project combined with the need for minimum volumes quickly available, it was decided to develop two identical pilot modules.

3.2 TECHNICAL OBJECTIVES

The **objective is to combine several *T-LUD pyrolysers* previously developed to make char from dry biomass. In the meantime the energy generated during this carbonization process can be used to dry the fresh biomass for the next char cycle**. Thus a charring-drying module (C-D module) has to be developed, utilizing this concept of "cycle" to increase energy efficiency.

Regarding the drying part of such module, it was decided to implement a "semi-continuous counter-flow dryer": the biomass, based on manual batch processing, moves in the opposite direction of the drying airflow.

The drying side becomes the challenge, with several technical points to address:

- ➲ How to balance the charring side vs. drying side: Is the energy (heat) released from carbonization enough for drying the quantity of fresh material needed?
- ➲ How to get the appropriate drying temperature from the charring process?
- ➲ How should the dryer be constructed to address these technical issues?

Requirements	
FP 1	To achieve necessary drying (down to 20-25% WB[3] moisture content) of the fresh coconut husk (80-90% WB moisture content)
FP 2	To carbonize 100% of the dry biomass, with average yield of 20% and homogenous fixed carbon content (range 65-85% according to the nature of biomass)
FC 3	To produce appropriate drying temperature and air flow
FC 4	To sustain the required drying conditions with energy from char production only
FC 5	To produce enough dry material AND char in order to ensure sufficient charbriquette production capacity
FC 6	To remove dried material
FC 7	To burn most of the pyrolytic gases
FC 8	To unload glowing char and stop pyrolysis
FC 9	To minimize environmental impact
FC 10	To optimize life span of equipment
FC 11	To ensure worker safety and ease of operation

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[3] Determined on *wet basis*

3.3 METHODOLOGY USED TO SIZE THE DRYER

1. What is the quantity of fresh material/product to be collected and dried? [kg]

According to:

➲ Nature of raw material, quantity of dried material needed, quantity of final product required (charbriquette production capacity)

2. How much moisture should be removed from the material/product? [kgH2O]

According to:

➲ Initial and final moisture content, quantity of dried material needed

3. What should the moisture evaporation rate be in the dryer? [kgH2O/hr]

According to:

➲ Ideal drying time, quantity of water to be removed

4. What is the pick-up efficiency of the air? [g/kg]

According to:

➲ Psychrometric chart, geographic location/climate

5. How much moisture 1m^3 of air can pick up from the material/product? [g/m^3]

According to:

➲ Average relative humidity of the outgoing air over the total drying period, final relative humidity of the outgoing air

6. What should the air flow rate be in the dryer? [m^3/hr]

According to:

➲ Average relative humidity of the outgoing air over the total drying period, final relative humidity of the outgoing air

7. How much thermal energy is necessary to evaporate water from the material/product? [kWh]

According to:

➲ Air flow rate + air characteristics, drying temperatures, drying time

3.4 TECHNICAL REQUIREMENTS

➲ **DRYING SIDE:**

Daily operations should allow the drying of 1700kg of coconut husk with two pilot modules. Coconut shell doesn't need extra drying since moisture content is already about 25%[4] on average.

Thus, one module has to dry 850kg of coconut husk with moisture content from 90% down to 25% within 7 hours.

Based on the previous methodology and integrating the worse atmospheric conditions (rainy season conditions), a drying temperature set at 100°C, a drying efficiency of 60%, a drying period of 7 hours, the specifications of the dryer should be as follows:

Air temperature	**Air flow**	**Thermal power**
100 °C	5609 m3/h	100 kW

➲ **CHARRING SIDE:**

Given the power of the *T-LUD pyrolyser v.01*[5], a combination of three units (when charring coconut husk) or two units (when charring coconut shell) should be working simultaneously per module. Then, in order to operate the module continuously without affecting the drying temperature, the power source should be doubled, with three units ending the carbonization process while the operator is preparing three more units to begin carbonization. Moreover, dimensional constraint –ground floor area- was also a concern. **Thus each module should have six *T-LUD pyrolyser* units.**

3.5 THERMAL ENERGY OUTCOME

The objective here is to check if the system is energetically balanced. The C-D module technically relies on the notion of a production cycle: charring process sustains the drying process, which is itself supplying the biomass for the next charring cycle.

Its design requires validation of its energetic balance, and how it should be operated.

See next page for detailed figures.

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[4] All percentages determined on *wet basis*

[5] 32kW with coconut husk, 50kW with coconut shell

3.5.1 ENERGY OUTCOME PER MODULE

🟧 Exothermic
🟦 Endothermic

process	step	Capacity per module [kg]	nb of TLUD	Dry matter [kg]	volatile mater / H2O [kg]	Duration of transformation per load [hour]	Instant power required/ generated [kW/module]	Energy for/from transformation [kWh/module]
DRYING	Wet > dry Husk	858	▨	300	557	7,0	100,0	700
1st CHARRING load	Dry Husk > char	_	3	11	43	0,75	93	49
2st CHARRING load	Dry Husk > char	_	3	11	43	0,75	93	49
3rd CHARRING load	Dry Husk > char	_	3	11	43	0,75	93	49
4th CHARRING load	Dry Husk > char	_	3	11	43	0,75	93	49
5th CHARRING load	Dry Husk > char	_	3	11	43	0,75	93	49
1st CHARRING load	Dry Shell > char	_	2	19	73	2,0	105	148
2nd CHARRING load	Dry Shell > char	_	2	19	73	2,0	105	148
3rd CHARRING load	Dry Shell > char	_	2	19	73	2,0	105	148
4th CHARRING load	Dry Shell > char (half load)	_	2	9	37	1,0	105	74
Total cocoshell per module [kg]=	322	TOTAL		**119**		**11**	**99**	**763**

3.5.2 CONCLUSION

The total energy required, including efficiency of equipment, does not allow one C-D module to be self-sufficient with coconut husk only. It requires 322 kg of coconut shell with maximum moisture content of 25%.

Module operation is energetically balanced with 5 loads of 3 *T-LUD pyrolysers* using coconut husk and 3.5 loads of 2 *T-LUD pyrolysers* using coconut shell.

Overall timing is positive in theory: charring side provides heat long enough to exceed the duration of drying. However, a daily charring time of 11 hours, excluding handling and cleaning turns to be a constraint since it is longer than usual working hours. Operation planning might have to integrate 2*8hours shift.

Two modules can produce 238kg of char per day, which gives 290kg[6] of charbriquette only.

Four modules in total would be required to sustain 550kg/day of charbriquettes. As stated in the introduction, during pilot phase only two modules will be implemented and have to be validated before any duplication.

An external source of char is likely to be found to sustain targeted production capacity.

3.6 ARCHITECTURE OF THE MODULE

Each module has two distinct sides: one is dedicated to carbonizing biomass material while providing heat from the combustion of pyrolysis gas; the other side is dedicated to drying biomass material in a semi-continuous counter-flow dryer. Air flue with blower connects the two sides.

Blower aims at collecting and circulating hot air from charring side to the drying side.

The dryer includes a long plenum which evenly distributes hot air to seven outlets where biomass material is piled up.

The fresh biomass is loaded into 100L metal drums *(see photo)* and stacks two containers high (a third one would be too high for the operator). This is believed to be a cheap and appropriate solution for the operators, even though the loading capacity per module is quite low.

Given the loading capacity of 30kg of coconut husk per drum, and considering size constraints (ground floor area), it was only possible to integrate seven air outlets into one module. This gives a loading capacity of: 7 outlets * 2 drums /outlet * 30kg /drum = 420kg of coconut husk per module.

The loading capacity per layer of 7 drums being 210kg, there should be 4 batches of 7 drums per module within 7 hours: The operator has to remove the lower layer of seven drums every 1h45min, before filling them up again with fresh coconut and put on top [layer].

Technical guidelines regarding the architecture:

- 6 independent *T-LUD pyrolyser* units (instantaneous power required=100kW)
- 7 air outlets for drums containing biomass for drying, 2 layers per outlet (capacity required=850kg/module)
- Insulated air plenum
- Insulated hot air collector, above each power source, with adjustable height
- Appropriate centrifugal blower, able to stand high temperatures
- Operational platform for easy and safe handling on both drying and T-LUD sections
- Minimal ground surface
- Operator should not be able to change any technical settings during operation

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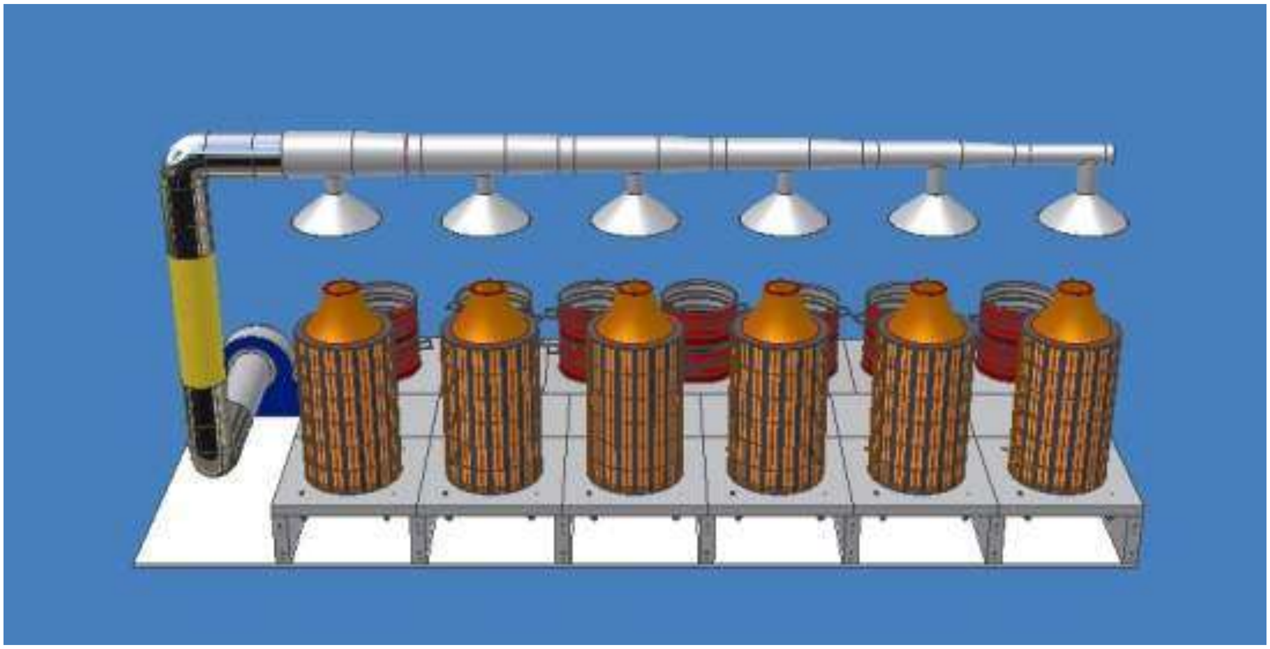
[6] 10% binder + 10% water



Above: 3D drawing of one C-D module

3.7 AIR FLUE DESIGN AND METHODOLOGY TO REACH EQUILIBRIUM

3.7.1 DESIGN

Previous calculations provide the necessary data to size the air flue, which is composed of three main components:

1. A *hot air collector*, collecting the hot air coming out of the six *T-LUD pyrolysers*. All air inlets having a different distance to the blower, each section has to be calibrated in order to have equal air flow.
2. A *blower*, providing the energy to circulate the air. Each blower is designed for a specific nominal working condition [m3/h] and [Pa]. Calibration of the air flue is to ensure optimal working condition.
3. A *drying plenum*, evenly distributing the air to the biomass to be dried. The static pressure inside the plenum must be as "Pressure plenum> atmospheric pressure" in order to have equal repartition of the drying air on each "column" of biomass.

Blower was sized based on the followings:

- ➲ Air flow required [m^3/h].
- ➲ Measured losses of pressure throughout the biomass bed [Pa].
- ➲ Estimated loss of pressure throughout the air flue [Pa].
- ➲ Mechanical and thermal constraints.

Locally available fan was:

Centrifugal fan – "squirrel cage", forward curved type
Belt drive (adapted locally)
Electric motor=4kW / 3ph
Volumetric flow rate= 4000-5700 m^3/h
Δpt= 1450-1400 Pa

3.7.2 METHODOLOGY TO REACH EQUILIBRIUM

Given the multiple air inlets above each *T-LUD pyrolyser*, and their respective distribution towards the blower, the next step is to measure and balance air flows separately to reach both the nominal working condition of the blower and equal air flows among the six air inlets.

NB: Due to the blower specifications, air velocity/flow rate was supposed to be enough, enabling the use of a Pitot tube.

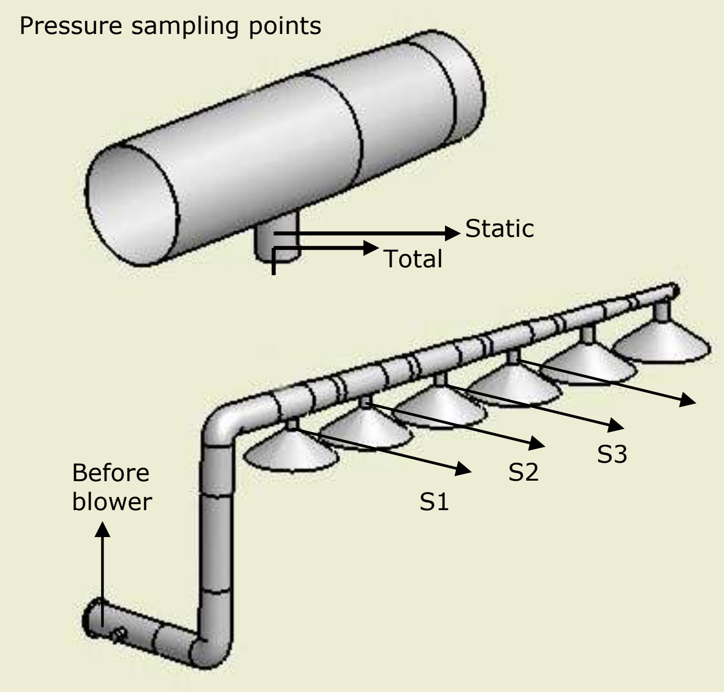
1. **Measure total pressure before and after main blower**
   a. If the blower is well sized: Δp total=< Δp nominal blower
   b. If Δp total< Δp nominal blower then Δp total should be increased
2. **Check equilibrium of air flows rates (inlet)**
   a. Measure with Pitot tube the total pressure at the 6 air inlets in order to calculate the air velocity and the air flow rates.
   b. Measure the static pressure inside the plenum to be sure:
      Pressure plenum> atmospheric pressure
3. **Re-calculate air inlet/outlet cross sections if the system is not balanced**
4. **Validation**

3.7.3 MEASURED AND CALCULATED FIGURES

Air flue				Plenum
Before blower		**After blower**		
Cross section [mm2]	17857	Cross section [mm2]		
Static pressure	-1120 Pa	Static pressure	-260 Pa**	+120 Pa (middle of the plenum)
Dynamic pressure	260 Pa	Dynamic pressure	580 Pa	
Total pressure	-820 Pa	Total pressure	280 Pa	
Total pressure (absolute value)= 1100 Pa				
Air velocity calculated: V=21.54 m/s **Air flow rate calculated (method 1): Q=5478 m^3/h**				

** Negative static pressure after the blower probably because the measure was done too close from the outlet, meaning in the low pressure zone (divergent)

Inlet sections	S1 (closest to blower)	S2	S3	S4	S5	S6
Cross section defined after test [mm2]	5672	5672	6359	6359	11304	13267
Air pipe diameter [mm]	85	85	90	90	120	130
hd measured [mmH2O]	54	68	60	54	32	9
Air velocity calculated [m/s]	31	34.8	32.7	31	23.9	12.68
Calculated flow [m3/h]	876	983	924	876	972	605
Total flow [m3/h]	**5236** (method 2)					



3.7.4 CONCLUSION

Based on experimental adjustments and measures, the air flue is designed and balanced for the following nominal point:

Q=5357 m^3/h (average value) under a **total pressure of 1100 Pa** (full load[7]: two layers of seven drums full of fresh biomass).

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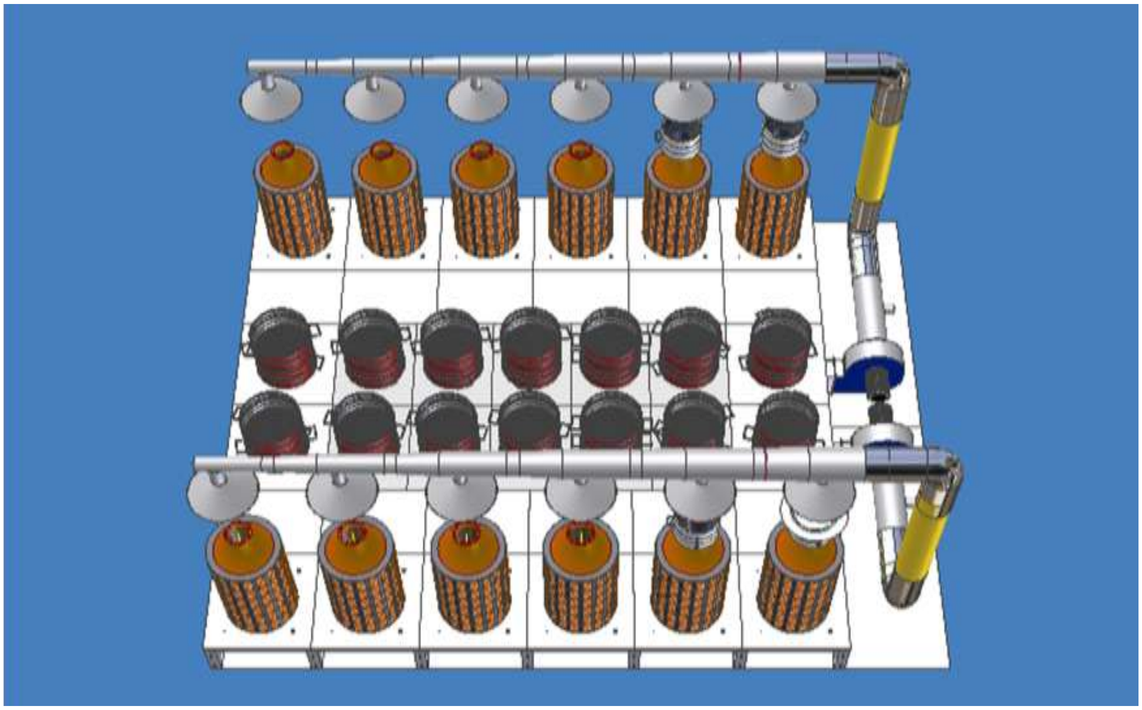
[7] 420kg/90% wb moisture content



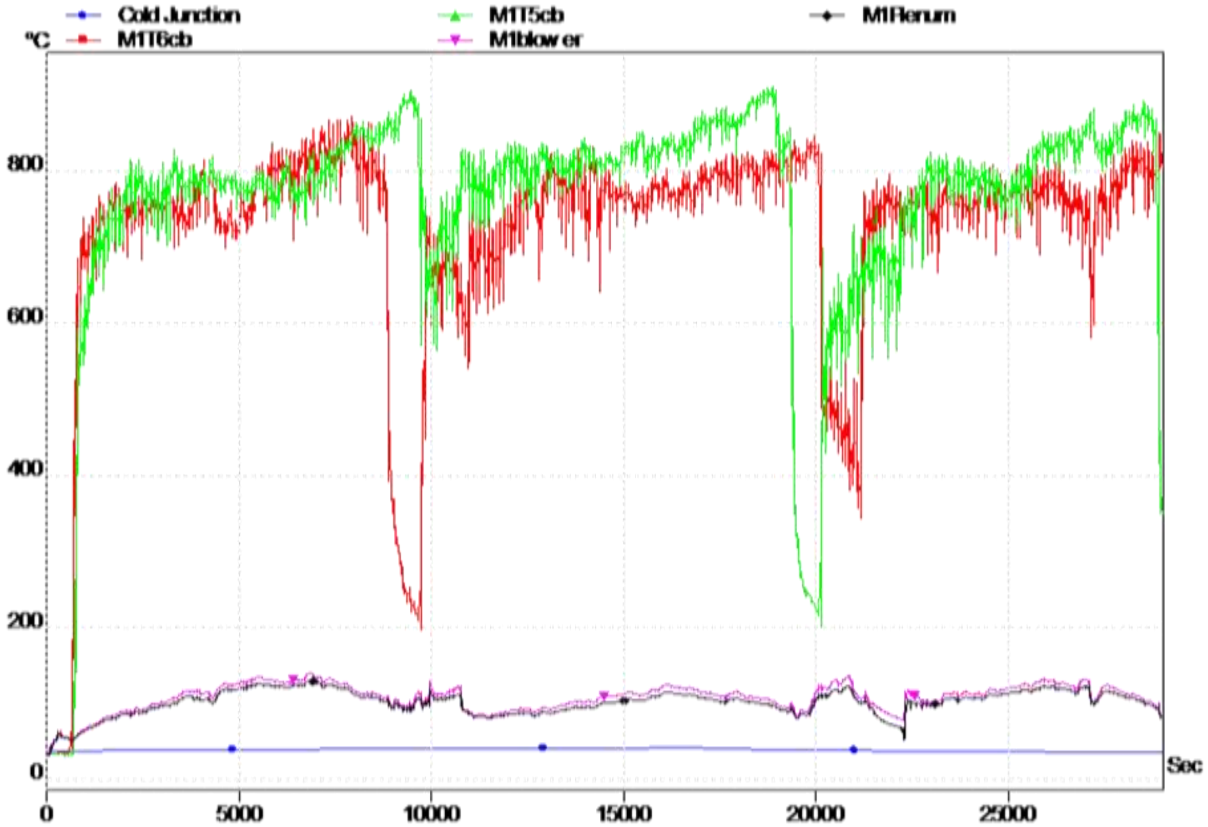
Above: 3D drawing of a set of 2 independent C-D modules.
Below: Same set of 2 C-D modules after their construction at SGFE, Cambodia.

3.8 VALIDATION TEST 1

3.8.1 OBJECTIVE

Validate the drying temperature of the C-D module during continuous operation.

3.8.2 TEMPERATURE RECORD



Module 1	Fuel: coconut shell		Total time: 8 hours			
Time [s]		ambient temperature [°C]	TLUD no6: flame temperature [°C]	TLUD no5: flame temperature [°C]	temperature at blower [°C]	temperature inside plenum [°C]
29031	AVERAGE	39	721	756	108	**102**
	MAX				141	131
	MIN				80	70

NB: TLUD no6=farthest from blower

3.8.3 OUTCOME OF TEST 1

Average drying temperature of 102°C was reached using 2 *T-LUD pyrolysers v.01* at the same time (2*50kW). **It validates thermal power and air flue specifications.** Thermal loss at the blower is significant even though special care was given to its insulation.

The drier the biomass, the more attention must be paid during operation to avoid any fire hazard since drying temperature may reach 130-150°C, even shortly.

3.9 VALIDATION TEST 2

3.9.1 OBJECTIVE

Record the drying temperature and time of the fully-loaded C-D module over a continuous operation process.
Check global efficiency of the C-D module.

3.9.2 TEMPERATURE RECORD

	ALL	overall process		Husk	3 TLUD operating together		shell	2 TLUD operating together	
Cold Junction	per burner	before blower	Plenum	per burner	before blower	Plenum	per burner	before blower	Plenum
°C	°C	°C	°C	°C	°C	°C	°C	°C	°C
ALL				Husk			Shell		
Average	534	97	96	536	93	89	534	95	99
Maximum	808	182	161	807	159	138	808	160	147
Mininum	21	42	46	21	49	52	52	42	46

3.9.3 FOLLOW UP ON EXTRACTED WATER

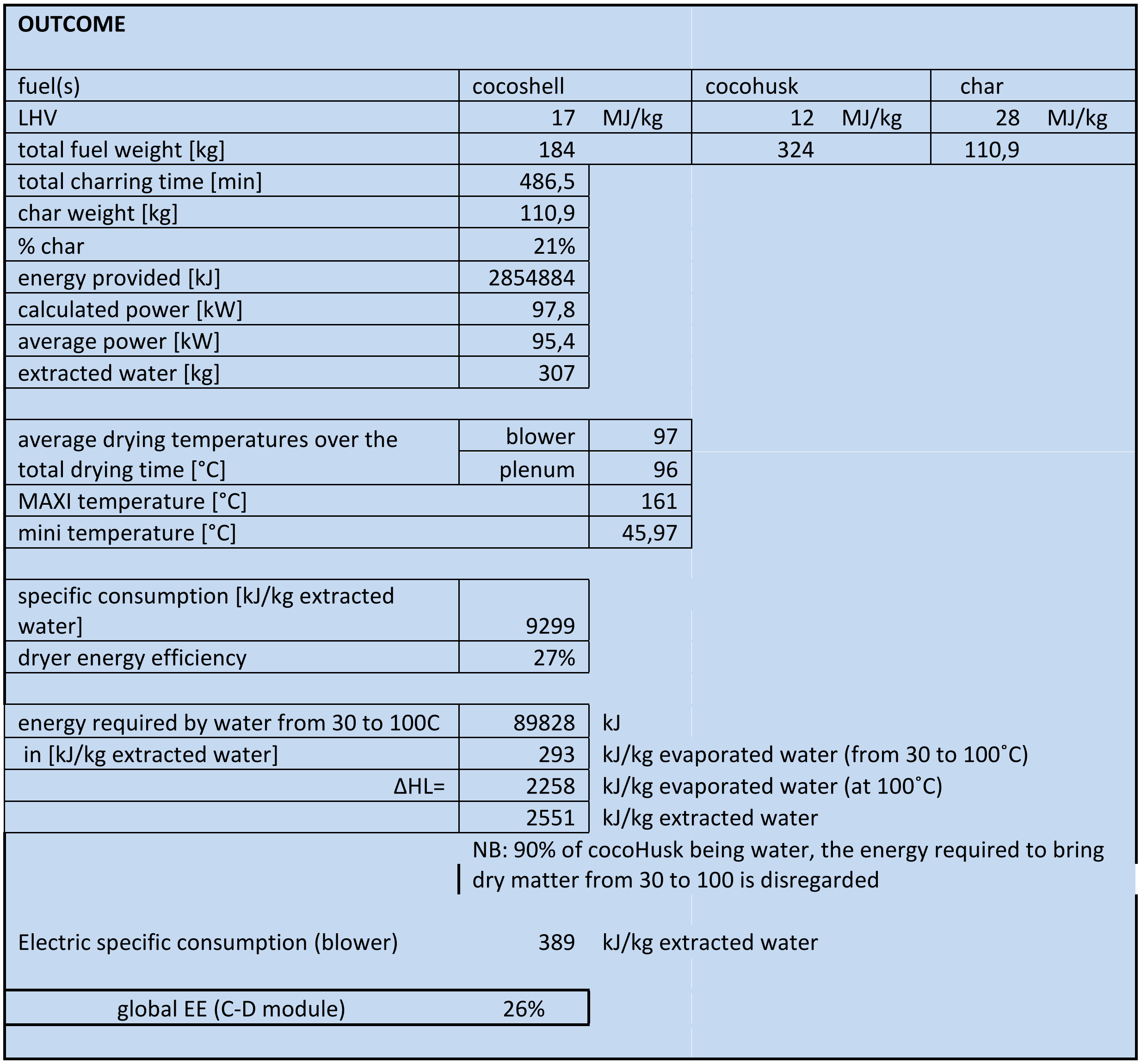
Module 1: Drying side

Weight of fresh coco before drying								
drums position	D1	D2	D3	D4	D5	D6	D7	TOTAL
top	30	30	30	30	30	30	30	210 kg
Buttom	30	30	30	30	30	30	30	210 kg
								420 kg
Weight of fresh coco **after drying 8hrs 20 mins** (after 6 loads of 3 TLUD -cocHusk- and 2 loads of 2 TLUD -cocoShell-)								
drums position	D1	D2	D3	D4	D5	D6	D7	TOTAL
top	18	7.5	7	8	7.5	9	7	64 kg
Buttom	12	7	7	5.5	6	4.5	7	49 kg
								113 kg

Extracted water	**307 kg**
Total loss of water	**73%**

D1 shows a drying heterogeneity: it is likely that its position being too close to the outlet of the blower, kinetic energy does not allow enough drying air to go through D1.

3.9.4 DATA SUMMARY



OUTCOME

fuel(s)	cocoshell		cocohusk		char	
LHV	17	MJ/kg	12	MJ/kg	28	MJ/kg
total fuel weight [kg]	184		324		110,9	

total charring time [min]	486,5
char weight [kg]	110,9
% char	21%
energy provided [kJ]	2854884
calculated power [kW]	97,8
average power [kW]	95,4
extracted water [kg]	307

average drying temperatures over the total drying time [°C]	blower	97
	plenum	96
MAXI temperature [°C]		161
mini temperature [°C]		45,97

specific consumption [kJ/kg extracted water]	9299
dryer energy efficiency	27%

energy required by water from 30 to 100C	89828	kJ
in [kJ/kg extracted water]	293	kJ/kg evaporated water (from 30 to 100˚C)
ΔHL=	2258	kJ/kg evaporated water (at 100˚C)
	2551	kJ/kg extracted water

NB: 90% of cocoHusk being water, the energy required to bring dry matter from 30 to 100 is disregarded

Electric specific consumption (blower)	389	kJ/kg extracted water

global EE (C-D module)	26%

3.9.5 OUTCOME OF TEST 2

Global charring-drying module efficiency has been 26%.

Real capacity is 51% less than planned, while taking 18.5% more time. Hypothesis on the drying efficiency was 60%, while real efficiency can be calculated as (0.26/0.73[8])*100=36%.

	Capacity (fresh coco husk) per module, per day [kg]	Time [hour]	Dry matter [kg]
Initial calculation	858	7	300
Real test	420	8.3	113

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[8] Efficiency of *T-LUD pyrolyser v.01* =73%

3.10 COST OF EQUIPMENT

Cost of 1 module					
Charring side	TLUD (concrete parts, metal part, conical part..)	6	Tlud	$ 280,95	$ 1 685,69
	Char box	7	box	$ 30,00	$ 210,00
	Combustion tub3	3	unit	$ 50,00	$ 150,00
	Sub total				**$ 2 045,69**
Charring side					$ -
	Concrete part(ground, plateform, side wall, lader)	1	set	$ 921,38	$ 921,38
	Blower (Blower set+modify to belt system + Installation	1	set	$ 880,00	$ 880,00
	Hot air system (hot air collector, insulation, installation)	1	set	$ 935,00	$ 935,00
	Plenum	1	set	$ 305,00	$ 305,00
	Drying drum	1	set	$ 252,00	$ 252,00
	Sub total				**$ 3 293,38**
		Grand total for only 1 module			**$ 5 339,07**

Important: cost of human resources excluded

4. CONCLUSION

4.1.1 ABOUT THE DESIGN

On the charring side, the calculation was not bad at all since an average drying temperature of 100°C has been reached inside the plenum.
Drying side is the main technical issue: inefficiency (36% instead of 60%) comes from **a low moisture removal ratio** since the air at the outlet of drying drums is not sufficiently saturated with water.
Design of the dryer should be adjusted in order to increase drying surface and quantity of the biomass by increasing the height of the biomass "column" and/or their number. Architecture of the dryer must integrate easy handling of several extra drums stacked.

4.1.1 ABOUT BIOMASS RAW MATERIAL

A low moisture removal ratio is surely due to the design of the dryer but also to the nature and bulk size of the raw material to be dried. Coconut husk has been the only material processed yet and its nature (thick, light and fibrous, with its rather impermeable skin on one side) and particle size (20cm*10cm*3cm) were of the worst.
Quantity of fresh biomass should be increased and particle size reduced in order to **thicken the layer forcing hot air to go throughout a longer path** allowing higher saturation.
Coconut husk is probably one of the most difficult materials to dry and **its initial moisture content should be lowered** before processing it into the C-D module (preliminary open-air solar drying).

Since drying efficiency is intimately linked to the nature and characteristics of the product to be dried, efforts should be made to source new raw biomass materials and facilitate their "drying behavior" by reducing their moisture content and increasing their total drying surface.

4.1.2 ABOUT CONSTRUCTION AND MATERIALS

Made of poor quality galvanized sheet, hot air collector does not last longer than six months: acidity of the smoke/gas, high temperatures and high humidity of atmospheric air cause the metal to rust and spoil *(see photo)*. This component should be made of stainless steel but the high investment cost becomes a barrier.
Insulation of the hot air flue has been quickly damaged: appropriate insulation materials are needed.
Metal support of the hot air flue has been bending after few months: a reinforced metal frame should solve this issue.
Galvanized unloading boxes for hot charcoal were a great source of expenses since they don't last more 2 months. Manufactured in stainless steel they have shown longer life span but still this particular component remains an issue: unloading design should be upgraded.

At this stage, limitation and/or barrier to reach viability are as follows:

- Char production is not yet at significant scale for low-cost industrial process;
- Drying efficiency must be increased;
- Metal components do not last. Air flue should be manufactured in stainless steel, but then the viability of the whole equipment might be threatened.

As such, **charring-drying module can't be validated**. However listed above improvements should significantly increase efficiency and might make the module a viable technology. Unfortunately time and financial resources were not sufficient to pursue development further.

Future R&D should investigate the possibility to get a common burner directly at the ground level. It would make the design and construction less complex and may reduce investment costs.

Such technology has been developed to process any biomass waste in the limit of appropriate nature (carbonaceous material), particle size and minimal moisture content[9].

New sources of biomass raw material (corn cobs, shells…) should be investigated while improving technically the dryer.

An accurate ratio "cost per kg of charcoal produced" would be an indicator to check the viability of such technology.

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[9] See GERES report "*Applied R&D on T-LUD Technology for charbriquette production in Cambodia – Part1-3: Introducing T-LUD stoves for use in charbriquette production plants".*

5. LINKS

www.drtlud.com	The Dr TLUD website is a comprehensive online reference for TLUD technology which is frequently updated with additions of new and historical content.
http://stoves.bioenergylists.org	This site contains topics and information discussed on the Biomass Cooking Stoves email list to help develop better stoves for cooking with biomass fuels in developing regions. The purpose of this "stoves" list is to promote the development and introduction of improved biomass-burning stoves.
www.charcoalproject.org	The mission of The Charcoal Project is to promote, facilitate, and advocate for the widespread adoption of clean burning technologies, sustainable fuel alternatives, and policies that support energy-poverty alleviation for those who depend on biomass as their primary fuel around the world. The Charcoal Project is supported by a global network of volunteer specialists that include scientists, conservationists, marketing, web, social development, and business experts.
http://www.pciaonline.org/	Welcome to the legacy website of the Partnership for Clean Indoor Air (PCIA). Over 2002-2012, 590 Partner organizations joined together through the Partnership for Clean Indoor Air to contribute their resources and expertise to reduce smoke exposure from cooking and heating practices in households around the world.
http://www.hedon.info/	HEDON Household Energy Network is the leading knowledge sharing and networking NGO for household energy solutions in developing countries. HEDON informs and enables the work of its members through information sharing, learning, networking, and facilitation of partnerships.
http://www.arecop.org	THE ASIA REGIONAL COOKSTOVE PROGRAM (ARECOP) was initiated in 1991 as a network that facilitates the development of effective improved cookstove and biomass energy programs at the household and small industry levels. The Network serves as a bridge for exchanges of information, skills, expertise and resources among diverse sectors.
www.sgfe-cambodia.com	SGFE (Sustainable Green Fuel Enterprise) was created in 2008 with the aim of alleviating poverty and reducing deforestation in Cambodia, as well as improving waste management in urban areas, by developing a local economic activity: manufacturing charcoal briquettes using organic waste.

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