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

PART 3-3

DEVELOPMENT OF CHARBRIQUETTE DRYER USING T-LUD TECHNOLOGY

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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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GERES Cambodia is particularly grateful to the implementing and funding partners of the overall project:

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 innovative drying equipment that uses the heat generated during carbonisation. This equipment decreases below 10% the moisture content of fresh charbriquettes, an aspect that is crucial to get a high-quality biomass fuel.

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.

[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 (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, after the development and validation of the T-LUD pyrolysers v.02 and v.03, the main objective is to use T-LUD technology and the recently developed *T-LUD pyrolysers* in order to respond to the energetic needs of the charbriquette production. In order to accomplish this goal, two pieces of equipment were developed:

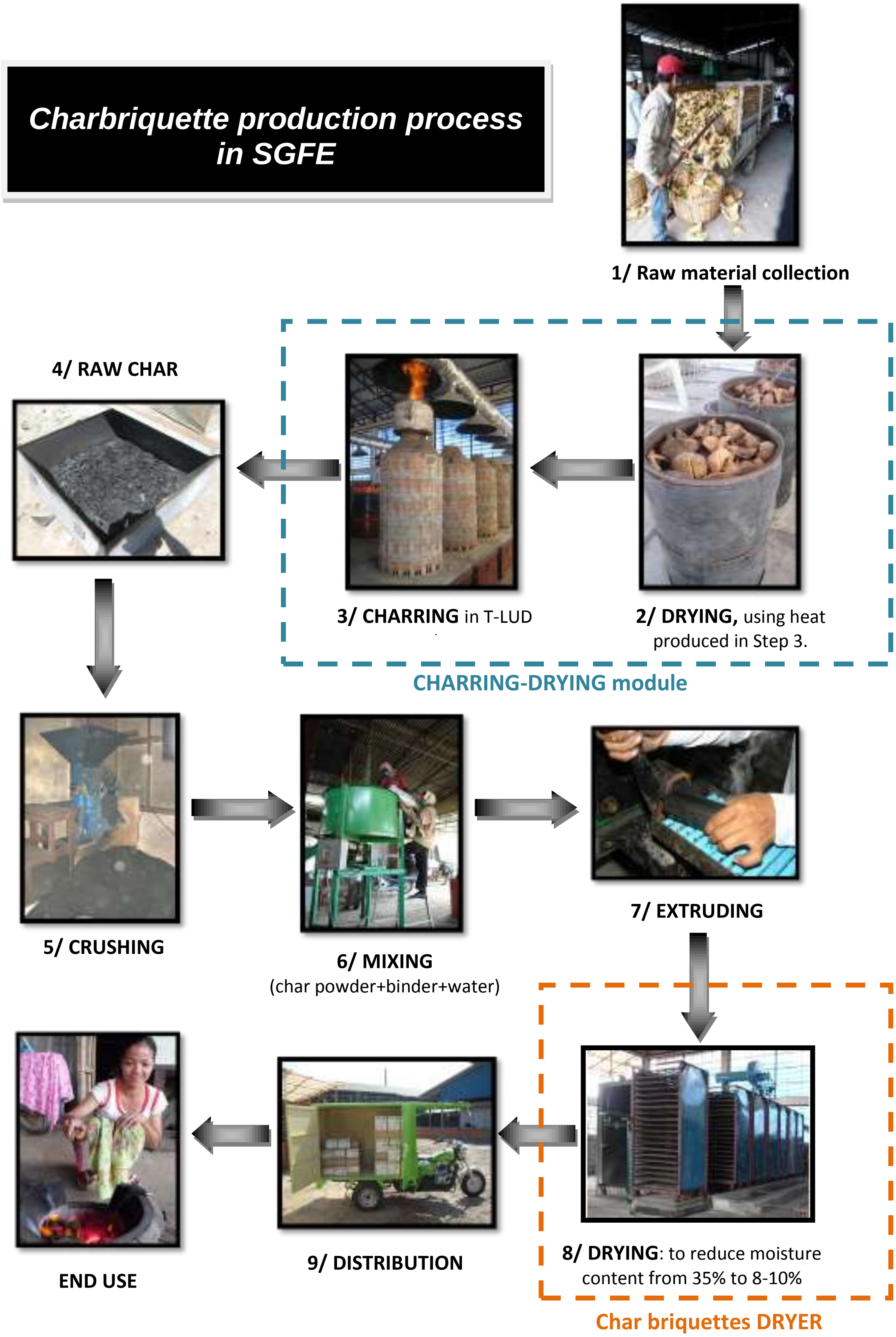
- ➲ **A charring-drying module** to undertake transformations 1 and 2
- ➲ **A charbriquette dryer** to undertake transformation 3

This report focusses on the charbriquette dryer 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.


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. CHARBRIQUETTE DRYER

3.1 INTRODUCTION

The moisture content of any solid biomass fuel greatly affects its energy content: the lower the moisture, the higher the energy content. For instance, the same stove may consume twice the quantity of fuelwood to produce the same amount of energy if the moisture content of the wood raises from 15% to 70%.

Charbriquette production requires addition of water along the process: water enables the binder to glue charcoal fines. It is therefore important to remove as much water as possible afterwards. However, reducing the moisture content below 8% is technically difficult, especially when industrial technology and process are not provided.

Removing water is also important to increase the resistance of the charbriquette.

It is important to note that this dryer was developed at quite a late stage of the project, under time and financial constraints. Corrective changes had to be undertaken due to capacity constraints**.**

3.2 TECHNICAL OBJECTIVES

The objective is to **use *T-LUD pyrolyser* previously developed to dry charbriquettes**. Here char production is not the main objective, but of course char produced will be added to the production chain.

Requirements	
FP 1	To reduce the moisture content of the fresh charbriquettes from 40% to 8%wb[2]
FP 2	To reach an initial nominal capacity of 500kg/day of dried charbriquettes
FC 3	To reach appropriate drying temperature and air flow
FC 4	To match drying performance and daily capacity and to ensure homogenous quality
FC 5	To enable convenient operation and handling
FC 6	To minimize environmental impact
FC 7	To optimize equipment life-cycle
FC 8	To ensure worker safety

3.3 PRELIMINARY CONCERNS

In order to assess charbriquette properties and drying requirements, two tests were performed at early stage:

- **Assessment of the maximum drying temperature for charbriquette.**

Following empirical tests, the limit was set to 150°C to avoid fire hazard (first ignition point lies at 180°C after 30min). Moreover, based on experience, a drying process characterized by high temperatures and brutal temperature leaps will negatively impact the quality of the charbriquette, causing it to crack. Thus drying temperature was arbitrarily set to 100°C.

[2] All percentages of moisture content determined on *wet basis*

- **Identification of the most important parameter for the drying process: air flow vs. drying temperature**

Two series of drying tests were conducted in laboratory on charbriquette samples. They led to the conclusion that, due to the specific density of charbriquette, the drying temperature was more important than the air flow.

3.4 Dryer design

The dryer design is **counter-flow "tunnel" type dryer with plenum and blower. Charbriquette is loaded on trays/trolleys moving toward the plenum and able to exit through a lateral door at the front.** Drying air goes in the opposite direction. As with the charring-drying equipment, heat comes from *T-LUD pyrolyser*.

Considering a production capacity of the extruder press of 120kg/h of briquettes (daily production of 1ton/8hours production), the design of dryer, and the capacity of trolleys, it was decided to build two shorter dryers instead of a long one where condensation might occur along the tunnel.

Such dryer being still at the R&D stage, objective is to build and validate one first.

Each dryer should allow a minimum capacity of 500kg/day of dried charbriquette.

Considering the amount of water to be removed, dryer must be designed and built to reach **nominal capacity of 750kg/day of fresh briquettes**.

3.5 METHODOLOGY

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 H2O/kg air]

According to:

- ➲ Psychrometric chart, geographic location/climate

5. How much moisture 1m^3 of air can pick up from the material/product? [g H20/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

3.6 TECHNICAL REQUIREMENTS

➲ **DRYING SIDE:**

Daily operation should allow the drying of 750kg of fresh charbriquettes, decreasing moisture content from 35-40% to 8-10% within eight hours. Drying temperature should be 100°C.

According to set parameters, calculation methodology gives the airflow and thermal power required:

Air temperature	Air flow	Thermal power
100 °C	2114 m3/h	38 kW

➲ **CHARRING SIDE:**

Given the calculated power of *TLUD pyrolyser v.03-40*, a single unit should be working at a time.

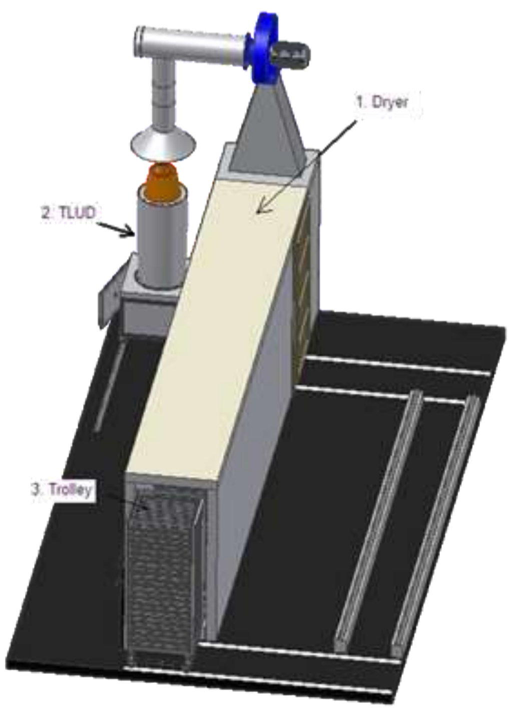
In order to continuously operate the unit without affecting significantly the drying temperature, the power must come from multiple sources: while one *T-LUD pyrolyser* is ending the carbonization process, the operator will be preparing the other one.

Thus the dryer should have 2 *TLUD pyrolysers* but a single hot air collector.

3.7 ARCHITECTURE OF THE DRYER

Technical guidelines regarding the architecture:

- Two independent *TLUD pyrolyser* units of 40kW each, easy to operate and switch from one to the other
- An insulated air plenum that ensures required airflow
- Insulated hot air collector
- Appropriate centrifugal blower, able to stand temperature
- Operational platform for easy and safe handling of heavy drying trolleys and *TLUD pyrolyser*
- Ability for continuous operation
- Minimal ground-surface
- No adjustable-settings, limiting operator's discretion



Left: 3D drawing of the charbriquette dryer design. Initial dimensions of the tunnel, including plenum, are 1.7m high and 3.8m long; loading capacity of 4 trolleys.

Above: charbriquette dryer during construction

3.8 Air flue design and methodology to reach equilibrium

a. Air flue design

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

1. A blower, providing the energy to circulate the air;
2. A hot air collector, collecting the hot air coming out of the T-LUD pyrolyser;
3. A drying plenum, evenly distributing the air to the drying briquettes.

Blower was sized based on the followings:	**Locally available fan was:**
➲ Air flow required [m^3/h]. ➲ Total pressure losses ➲ Mechanical and thermal constraints.	Centrifugal fan – "squirrel cage", forward curved type Belt drive (adapted locally) Electric motor=1,5kW / 220V Volumetric flow rate= 2600-3600 m^3/h Δpt= 750-500 Pa

b. Methodology to reach equilibrium

In order to reach nominal working condition, total pressure losses of the blower were increased between plenum/tunnel. The aim is also to get a homogenous repartition of the hot air flowing on each tray from each trolley.

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

	air speed [m/s]	cross section [m2]	calculated air flow [m3/h]
before blower	16	0,0572	3292
after blower	15	0,0636	3340
plenum	14	n/a	n/a

c. Conclusion

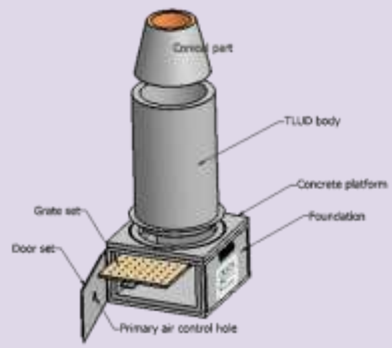
Based on real tests and measures, the air flue was designed and balanced for the following nominal point: **Q=3300 m^3/h under a total pressure of 720 Pa** (round figures).

Nominal working condition will be changed in case drying temperature <100°C.

4. TECHNICAL SPECIFICATIONS OF *TLUD* PYROLYSER V.03-40

Main change between *TLUD pyrolyser* v.02 and v.03: concentrator, inner shield and grate were made of refractory cement in order to extend life spam. Dimensions remain the same.

Charring yield was set back to 20%.

	T-LUD pyrolyser v.03-40 - *dual skin*
Dimensions:	Fuel canister: inner diam300mm*1000mm height, unloading chamber: 700*700*350mm. "dual-skin" canister: inner refractory shield and external metal cylindrical body 
Materials:	Concentrator: ''cold'' ceramic made of refractory cement, canister: specific refractory bricks, unloading chamber: brick+ Portland mortar /metal door
Primary air:	Natural draft, inlet throughout the grate, airflow control at the door of the unloading chamber Primary air flow: n/a
Secondary air:	Natural draft, 360° outlet Secondary air flow: n/a
Heat exchanger for secondary air:	Coaxial metal cylinders: between external body and fuel canister
External insulation:	None (surface temperature=75°C)
Grate:	Refractory grate on a metal frame, ''guillotine'' mechanism
Power:	40kW (coco Shell, moisture content=21%, EC=17MJ/kg)
Energy conversion efficiency*:	85%
Approximate cost:	1000 USD (labor not included). Refractory cement was 40% of the cost since it had to be imported.
Charring yield:	22% on average
Specific fuel consumption :**	18,3 kg/h (on average) Batch mode: 33kg/load, 108min (coconut shell particle size 20mm*30*5)
Specific charcoal production* :**	4 kg/h (on average) Batch mode: 7kg/load, 108min
Maximum raw material moisture content:	25%

*Energy conversion efficiency defined as=("theoretical energy from the fuel"-"energy from the remaining char"- thermal losses from canister and concentrator) / "theoretical energy from the fuel"

**Specific fuel consumption=weight of fuel/charring time

***Specific charcoal production rate=weight of charcoal produced/charring time

** Careful, figures may change according to raw material size and moisture content (power being fixed). Figures given here are indicative.

5. Charbriquette dryer: validation tests

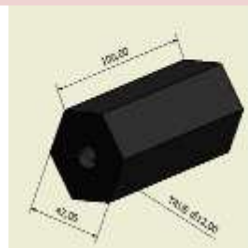
5.1 Objective

The objective of the tests is to check and validate the design of the drying equipment (drying temperature, drying time, equipment efficiency, operations, materials, etc…) and/or to point out potential problems.

The outcome of the tests eventually suggests the improvements required for the technical validation of the equipment.

5.2 Validation test 1

5.2.1 Test summary

Fuel	Crushed coconut shell, 22.4%MC, 28kg/TLUD*5 loads= 140kg
Briquettes to be dried	nature :« Premium » type briquette size: hexagonal shape 42mm side to side on the diameter / length 100mm initial weight (wet) : 760 kg final weight (dry) : 478 kg 
Global energy efficiency [%]	44
T-Lud efficiency[3] [%]	84
Fuel used [kg]	140
Total drying time [h]	13.2
Kg of fuel used/kg of dried briquette	0.29
Kg of fuel used/kg of extracted water	0.50
Capacity [kg_dry]	478
Drying rate [kg_dry/h]	36.2
Final moisture [%wb[4]]	n/a
Operation mode	batch

[3] Calculated as: *1- (calculated thermal losses / (energy from fuel - energy from charcoal produced))*

[4] *wet basis*

5.2.2 DETAILED FIGURES

OUTCOME					
fuel(s)	cocoshell		char		
LHV	17	MJ/kg	28	MJ/kg	
total fuel weight [kg]	140		16,7		
total charring time [min]	691,0				
char weight [kg]	16,7				
% char	12%				
energy provided [kJ]	1614825				
calculated power [kW]	38,9				
average recorded power [kW]	39,1				
extracted water [kg]	282	average calculated from samples:			
			42,3	kg recorded during the test	
average drying temperatures over the total drying time [°C]	After plenum (1st trolley)	107			
	Outlet (middle)	45			
MAXI temperature after plenum [°C]		144			
mini temperature after plenum [°C]		44			
specific consumption [kJ/kg extracted water]	5726				
global dryer energy efficiency	46%				
total weight of wet briquette [kg]	760				
total weight of evaporated water [kg]	282	(calculated average)			
energy required to bring charcoal from 30°C to 100°C	27705		Cp charcoal=0.828kJ/kg		
energy required to bring water from 30°C to 100°C	82513		Cp eau=4.18 kJ/kg		
energy required to evaporate water	636756	with ΔHL=	2258	kJ/kg evaporated water (at 100°C)	
TOTAL energy required to evaporate water [kJ/kg]	2649				
Electric specific consumption (blower)	253	kJ/kg extracted water			
global EE (blower included)	44%				

NB: test conducted during rainy season (ambient air: 77% humidity, 31°C)

5.2.3 Temperature and humidity record

➲ **Temperature**

Recorded average drying temperature at plenum is 107°C while the objective was to get 100°C. Being below 150°C, and given there is no regulation system, such mistake can be accepted. Nevertheless fire hazard may come from peak temperature (144°C max) as humidity lower.

Even though peak temperature may be short, such dryer requires care from operator all along the process.

➲ **Humidity**

The evolution over 13 hours of air humidity at the outlet of the dryer shows a drying heterogeneity: from the third trolleys, briquettes at the lower level are not as dried as the ones on top.

Such problem can be overcome with semi-continuous drying operation. Architecture of the dryer allows removing the first trolley while pushing forward the fourth which then becomes third. This particular move will leave space for a new trolley.

This test also shows that out-coming air is not water-saturated, even from the beginning of the process. **The tunnel's length has to be extended in order to increase global efficiency.**

5.2.4 Conclusion of test 1

Major problem of this test comes from the non-available final moisture content of the briquette. Even though it is believed to be around 10%[5], some figures can't be reliable enough.

Nevertheless **it was important to validate drying temperature, meaning thermal power and airflow. Overall dryer efficiency is assumed to be 44%.**

Drying time was 65% longer than planned within the initial calculation.

Several reasons may explain that difference:

- Drying efficiency has been 52%[6] instead of 60% initially assumed
- During test 1, dryer was operated on a "batch mode" instead of "semi-continuous mode"
- Final moisture content is unsure

Given the record of humidity and also because of the need for bigger production volumes, it was decided to increase dryer's capacity.

[5] Determined on *wet basis*

[6] Defined as "Global dryer efficiency / T-LUD efficiency =0,44/0,84=0,52"

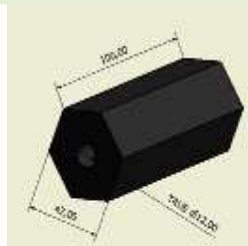
5.3 Final architecture of the dryer

In order to increase drying efficiency, the tunnel is extended from 3.8 to 6 meters long which brings total capacity up to 1.3ton/day of fresh charbriquettes (7 trolleys). Overall design remains the same.

5.4 Validation test 2

5.4.1 Test summary

This test was conducted over two days with overnight interruption in-between.

Fuel	Crushed coconut shell, 21.5%MC, 33kg/TLUD, 321kg
Briquettes to be dried	nature :« Premium » type briquette size: hexagonal shape 42mm side to side on the diameter / length 100mm initial weight (wet) : 1357 kg , 40%wbMC[7] final weight (dry) : 928 kg 
Global energy efficiency [%]	44
T-Lud efficiency[8] [%]	72 (inner refractory shield missing)
Fuel used [kg]	321
Kg Fuel used/kg of dried briquette	0.35
Kg Fuel used/kg of extracted water	0.75
Duration [h]	17.8
Kg of extracted water/hour	24.1
Capacity [kg_dry]	928
Drying rate [kg_dry/h]	52.2
Final moisture [%wb]	8.07 (from laboratory)
Operation mode	batch

[7] Wet basis moisture content

[8] Calculated as: *1- (calculated thermal losses / (energy from fuel - energy from charcoal produced))*

5.4.2 TEMPERATURE RECORD

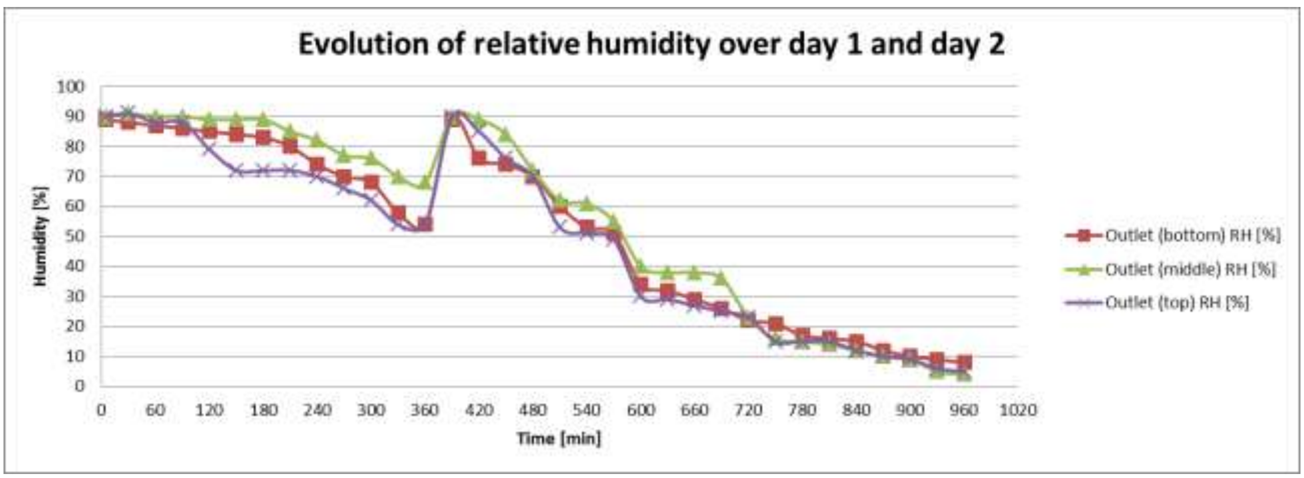
	Day 1 and 2 combined			
Time	Cold Junction	Inside plenum	Next to trolley1	End of dryer
Seconds	°C	°C	°C	°C
Average	35	100	98	48
Max	39	169	152	65
Min	29	37	31	28

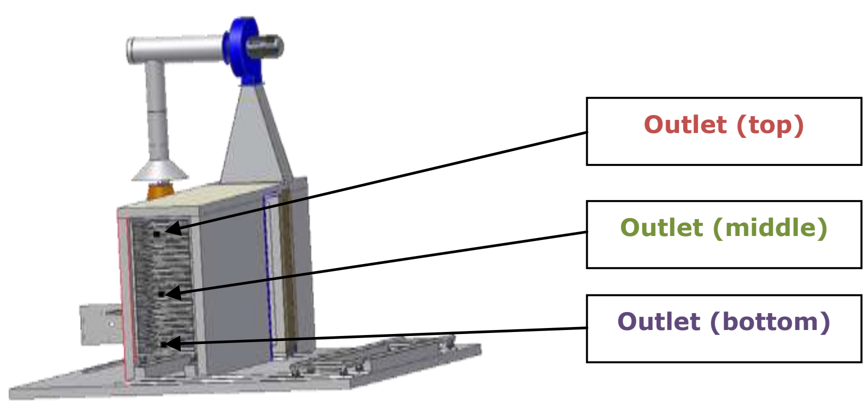
Average drying temperature at the beginning of the tunnel is 98°C (next to trolley 1). Since the objective was set at 100°C, it confirms the design of air flue and the drying temperature.

Along the dryer, temperature drops to about 50°C. Being 150°C the highest temperature possible, and given the existing peaks of temperature, it is not possible to increase temperature at plenum in order to raise temperature inside the tunnel.

Here, temperature of 152°C is unusual and comes from inappropriate operation on *T-LUD pyrolyser*. Fire hazard may come from such peak of temperature as humidity lower.

5.4.3 HUMIDITY RECORD





Above: sampling point location on the dryer

The relative humidity of the air coming out during the first 3 hours is around 90%, this being an indicator of the dryer efficiency. At the end of the process, there is no significant heterogeneity between bottom and top of outlet.

Briquettes seem to absorb ambient humidity when left overnight in the dryer off. **Even though the drying time is long, operations have to be carried out continuously in order to optimize time and energy. Production planning must address this particular problem.**

5.4.4 Outcome of test 2

This test validates drying temperature, air flue design and upgraded drying capacity.

Drying efficiency has risen up to 61%[9] but is counter-balanced by a lower efficiency of T-LUD pyrolyser. **Overall dryer efficiency still amounts to 44% while capacity has almost doubled.**

Main reason comes from the "batch mode operation" ran over two days WITH interruption overnight: it took three hours on the second day to reach back final relative humidity of the first day. A significant part of the energy and time at the beginning of the second day is spent to warm up mass of the dryer and briquettes again.

Dryer should be operated on a "semi-continuous mode" WITHOUT any interruption, thus requires specific operation planning.

Even though possible peak temperature may be short, such dryer requires attention from operator all along the process.

[9] Defined as "Global dryer efficiency / T-LUD efficiency =0,44/0,72=0,61"

5.5 VALIDATION TEST 3: ONE WEEK OPERATION

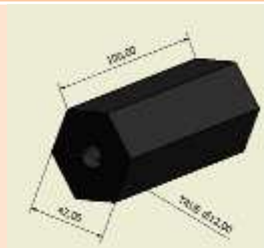
5.5.1 OBJECTIVE

The test objective is still the validation of equipment efficiency, drying temperature and TLUD. However, **priority here is to validate the "semi-continuous mode" and especially the rotation time between two trolleys while making sure moisture content has decreased to 8%.**

5.5.2 TEST SUMMARY

This test was conducted on a semi-continuous mode, over five days[10].

Unfortunately it could not be conducted without any overnight interruption.

Fuel	Crushed coconut shell, 22%MC, 46kg/TLUD, 920kg
Briquettes to be dried	nature :« Premium » type briquette size: hexagonal shape 42mm side to side on the diameter / length 100mm initial weight (wet) : 3995 kg total final weight (dry) : 2522 kg total initial moisture content=42%wb final moisture content=8%wb 
Global energy efficiency [%]	47
T-Lud efficiency[11] [%]	83
Fuel used [kg]	920
Kg of fuel used/kg of dried briquette	0.36
Kg of fuel used/kg of extracted water	0.62
Kg of extracted water/hour	24.3
Duration [h]	60.5
Capacity [kg_dry]	2522
Drying rate [kg_dry/h]	41.7
Final moisture [%wb]	8 (quality control check)
Operation mode	Semi-continuous

[10] Day1:9hours operation; day2:12hours; day3:12hours; day4:12hours; day5:9hours

[11] Calculated as: *1- (calculated thermal losses / (energy from fuel - energy from charcoal produced))*

5.5.3 DETAILED FIGURES

DATA				
fuel(s)	cocoshell		char	
LHV	16	MJ/kg	28	MJ/kg
total fuel weight [kg]	920		180,8	
total charring time [min]	3585,0			
char weight [kg]	180,8			
% char	20%			
energy provided [kJ]	8038528			
calculated power [kW]	37			
average power [kW]	37			
extracted water [kg]	1473			
average drying temperatures over the total drying time [°C]	After plenum	109		
	Middle outlet	n/a		
MAXI temperature [°C]		128		
mini temperature [°C]		31		
total drying time [min]	3630			
specific consumption [kJ/kg extracted water]	5457			
dryer energy efficiency	49%			
total weight of wet briquette [kg]	3995			
total weight of evaporated water [kg]	1473,0			
energy required to bring charcoal from 30°C to 100°C	146175		Cp charcoal=0.828kJ/kg	
energy required to bring water from 30°C to 100°C	431000		Cp eau=4.18 kJ/kg	
energy required to evaporate water	3326034	with ΔHL=	2258	kJ/kg evaporated water (at 100˚C)
TOTAL energy required to evaporate water [kJ/kg]	2650			
Electric specific consumption (blower)	222	kJ/kg extracted water		
global EE (bower included)	**47%**			

5.5.4 TEMPERATURE RECORD

Drying temperature is quite regular all along the process without any significant overheating. Recorded average drying temperature next to trolley1 is 109°C while the objective was to get 100°C. Since there is no regulation system the mistake can be tolerated, especially that it is still below firing temperature of briquettes.

Average temperature [°C]	109
Max	128
Min	31

5.5.5 OUTCOME OF TEST 3

Even though daily capacity was not set at the maximum (between 500kg/day and 850kg/day), it was possible to validate a **rotation time of 2h30 between 2 trolleys**. Quality control must be implemented and operator trained to ensure that final moisture content lies within acceptable limits (below 10%wb).

The overall dryer efficiency amounts to 47%.

However, it could be even higher if:

- **Daily drying capacity is always at the maximum (1300kg/day)**
- **Drying operation is run without any interruption**

It is likely that dryer capacity can still be increased with extra-extension of the tunnel.

6. COST OF EQUIPMENT

Cost of 1 dryer set (year 2011)					
TLUD	TLUD	2	Unit	$ 1 000,00	$ 2 000,00
	Combustion tube	2	pc	$ 35,00	$ 70,00
	Char box	2	pc	$ 22,00	$ 44,00
Trolley	Trolley	10	unit	$ 200,00	$ 2 000,00
	Rail system	1	set	$ 250,00	$ 250,00
All Concrete body	Dryer body	1	set	$ 700,00	$ 700,00
Hot air system	Blower +mofification+installation	1	set	$ 500,00	$ 500,00
	Hot air collector	1	set	$ 50,00	$ 50,00
	Installation and insulation	1	set	$ 180,00	$ 180,00
	Electrical control panel	1	set	$ 50,00	$ 50,00
				Total	**$ 6 152,40**

7. CONCLUSION

Several problems were faced during the development of the illustrated drying equipment. R&D was conducted during the project and concluded almost at the end of it. Besides technical difficulties, main concerns were the viability of the business plan and the resulting job security for the 15 new employees. Ensuring low-cost production, high production quality and establishing a new market were the main challenges. It is important to keep in mind that a drop in quality may seriously threaten the growing demand of the newly created market!

Further tests should be conducted in order to better evaluate the dryer efficiency, especially with NO INTERRUPTION during drying operation while daily load is kept at the MAXIMUM CAPACITY. In such condition, overall dryer efficiency might amount to 60% due to a drying efficiency rising up to 70%.

The drying process would require specific management and should include night shifts for round-the-clock operations in order to maximize production capacity while making sure drying time is not shortened.

This equipment has a potential for interesting applications. It also presents the advantage of producing good quality charcoal from the fuel (bulk biomass residues) inside *TLUD pyrolyser*.

Design is simple (no electronic regulation, no high-tech material, no "highly-qualified" maintenance skills…) and operations easy (no adjustable settings). Made of refractory cement parts, *TLUD pyrolyser v.03-40* is now resistant, reliable and efficient.

On the other side, the trolleys, when loaded, are heavy to carry; simple mechanization should be added to help handling.

Moreover, operations require attention and precision to avoid fire hazard and ensure quality control. A simple regulation system could be implemented in order to avoid fire hazard: a temperature sensor could drive a by-pass before blower's inlet in order to dilute ambient air with hot air.

Overall efficiency of the dryer might be maximized by increasing loading capacity.

Besides, efficiency could be improved by a better external insulation. It would increase temperature inside tunnel and reduce the amount of time needed for drying.

Variable costs of the drying process were estimated as follows:

		days of production	250	per year
		biomass fuel	75	US$/ton coconut
		electricity	0,18	US$ / kWh
		forex	4023	Riels / US$ (nov 2012)
		commercial value of charcoal produced	200	Riels / kg charcoal
Fuel consumption	0,36479	kg coco /kg dry briquette	0,027359	US$/kg dry briquette
Electricity consumption	0,036	kWh/kg dry briquette	0,006397	US$/kg dry briquette
Depreciation over 3 years	8,203	US$/ day of production	0,016262	US$/kg dry briquette
Sub total cost (labor excluded)			0,05	US$/kg dry briquette
Sub total cost (labor excluded)			201	KH riels
Char produced (income)	0,071689	kg/kg dry briquette	14	KH Riels
		TOTAL cost (labor excluded)	187	KH riels

Moreover, the cost of labor (here considered a fixed cost) needs to be taken into account, especially in case of round-the-clock operations since night shifts could result in higher operating costs.

The dryer implemented and operating at SGFE needs a follow up on a longer period before final validation (material life-spam, handling, drying cost and viability, troubles…). But so far it has shown a good potential for wider dissemination.

8. 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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