RICE HUSK GASIFIER STOVE PERFORMANCE TESTING REPORT

SNV SMART DEVELOPMENT WORKS

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General Introduction

As an agricultural country, Vietnam has a high potential for biomass energy. Main types of biomass in Vietnam consist of firewood, rice husk, agricultural residue from plants, livestock wastes, urban wastes and other organic wastes. It can be converted into product gas for households, heat supplies, power generation and etc. It is estimated that about more than 60 million tons of biomass is generated every year from agricultural residues [1]. However, so far only from 30-40% of biomass is used for energy purposes, mainly as fuel for cooking in households and small amount used for about 150 MWe electricity generations in 42 sugar mills [2]. The remain biomass types as the surplus rice husks and paddy straw are disposed by direct burning in open heaps, which results in loss of energy as well as emission of various pollutants to the atmosphere. Beside that, using biomass gasifier stove for cooking in rural areas of Vietnam show a high potential because it has a lot of advantages compared to direct burning in the cookstoves as high thermal efficiency, less smoke and less particulate matter emissions.

Recently, plenty of biomass stove gasifier models are presenting in the cookstove market in Vietnam. If we consider their gasification process and syngas flow direction, it can be classified by 2 types: One is top-lid up draft (TLUD) gasifier stoves which are quite simple design, easy start up and operation and cheap price, however, their life time in operation is short, combustion time per batch is also short. The other one is updraft gasifier stoves which can be adjusted secondary air for enhancing combustion and reducing pollution emissions but It is quite complicated stove and hard to operate, skillful labor for operation is needed, investment cost is about ten time higher than TLUD gasifier stoves.

Among gasifier stoves which one is better performance is still remain a lot of questions. Therefore, 4 gasifer stoves and a traditional stove were selected and tested at the LHERE stove testing facility using a modified form of the version WBT 4.2.2. The original protocol is available online [3]. The stoves were tested for thermal efficiency, emissions of CO, PM2.5, time to boil, specific fuel consumption, time to burn off per batch and stove temperature safety. The Laboratory results from emissions and efficiency testing and conclusions regarding usability of the stoves are presented in this report.

1. METHODS

1.1. *Stove tested*

Base upon these criteria as well as availability of the cookstoves for testing, the following five stoves shown in Figure 1 were chosen for inclusion in the evaluation.

Table 1: Cookstove models

Stove model	Technical description
Rua Stove (1) 	Material: Stainless steel stove, Two layers Top-draft gasifier, 12V-DC fan attached (with adapter, 220V-AC supply is ok) Outer diameter: 30cm, Inner diameter: 25 chm; Height: 45 cm Load of rice husk (per batch): 1.3- 1.5kg Burning time: 30-45mins
Viet Stove (2) 	Material: Metal sheet stove Top-draft gasifier, 12V-DC fan attached (with adapter, 220V-AC supply is ok) Diameter: 18cm, height: 60cm Load of rice husk (per batch): 1.4-1.5kg Burning time: 30-35 mins
Thuan Phu Stove (3) 	Material: metal sheet + infrared burner (IRBC) Top-draft gasifier, separate burner, 220V-AC fan Diameter (reactor): 50cm, height: 80cm Burner width: 30cm, burner length: 60cm Load of rice husk: N.A Burning time: 2hours
Traditional Stove (4) 	Material: Metal sheet stove Open combustion of rice husk, no fan Diameter: 50cm, Height: 40cm Load of rice husk: 2-3kg Burning time: Continuously
SPIN Stove (5)	Material: stainless steel stove

	Two layers Top-draft gasifier, 12V-DC fan attached Outer diameter: 20cm, height: 60cm Load of rice husk: 1,36 kg Burning time: 30-45 mins

There were no instruction on using the stoves but the owner of each gasifier stove was invited to operate their stove except the Rua stove as its owner is not available. So we did several practice runs with Rua stove and traditional stove prior to testing. Each stove was operated in order to maximize its efficiency, including varying the power when possible by manipulating airflow. Therefore, each gasifier stove was conducted by the same cook, same measurement methods to ensure a consistent result.

Figure 1: From left to right: Thuan phu Stove (3), SPIN Stove (5), Viet Stove (2), Rua Stove (1), Traditional Stove (4)

1.2. Fuel tested

Rice husk was uses for all testing. 150 kg of rice husk was bought from the same resource, it was packed with plastic bags and transported to Stove testing laboratory. Each Rice husk bag was analyzed using standard oven-dry procedures before testing in the stoves. In general, rice husk moisture contents of samples are quite similar which are range of 10 to 11,5 %.

1.3. Test system

All testing was performed under controlled conditions at Stove Testing Laboratory, LHERE. The test system consists of a stove platform and an exhaust hood which draws gases upward where they are mixed and sampled (Fig. 2a and Fig. 2b). CO emissions, PM2.5 emission, water temperature, stove body temperature, fuel weight were measured and recorded in real time by testing facilities that were listed in Table 2 in detail.

Figure 2a: Above: The stove testing system at Stove Testing laboratory, LHERE. Below: a side view of a stove (the Viet stove) on the testing platform, with the front door of the exhaust hood open to view the set -up.

Table 2: Testing facilities

<table>
<tr><th>N^o</th><th>Name of Items</th><th>Model (Number)</th><th>Specifications</th></tr>
<tr><td>1</td><td>True RMS Multimeter with Temperature</td><td>FLK-87-5</td><td>• Measure up to 1000V AC and DC
• It also has a built-in thermometer with TC probe
• Withstands hazardous 8,000 volt spikes caused by load switching</td></tr>
<tr><td>2</td><td>ERO TTX 100 (-50-350 ^{o}C) Germany</td><td>TTX-100</td><td>- Temperature range: -50 … +350^{0}C
- Accuracy: ± 0.8^{0}C hoặc ± 0.8%.</td></tr>
<tr><td>3</td><td>BACHARACH Combustion annalyser</td><td>PCA®3 (24-7320)</td><td>Measurement Ranges
<table>
<tr><td>Primary/Ambient Air Temperature</td><td>-20 to 536^{o}C</td></tr>
<tr><td>Stack Temperature</td><td>-20° to 1200°C</td></tr>
<tr><td>Oxygen</td><td>0 to 20.9%</td></tr>
<tr><td>Carbon Monoxide (H_2Compensated)</td><td>0 to 4,000 ppm</td></tr>
<tr><td>Carbon Monoxide, (High Range)</td><td>4,001 to 20,000 ppm</td></tr>
<tr><td>Nitric Oxide</td><td>0 to 3,000 ppm</td></tr>
<tr><td>Nitrogen Dioxide</td><td>0 to 500 ppm</td></tr>
<tr><td>Sulfur Dioxide</td><td>0 to 5,000 ppm</td></tr>
</table></td></tr>
<tr><td>4</td><td>Electronic weighing scale</td><td>Jadever</td><td>Max weight 15kg, steps of 0,5g</td></tr>
<tr><td>5</td><td>Multi meter (temperature, Humidity, air velocity)</td><td>TSI 8347</td><td>- Velocity range 0-30 m/s; Accuracy ± 3%
- Humidity range 0- 95%; Accuracy ± 3% Rh
- Temperature range 0-60 ^{o}C; Accuracy ± 3% Rh</td></tr>
<tr><td>6</td><td>Portable infrared thermometer</td><td>UX-10P</td><td>Temperature range 900-3000 ^{o}C</td></tr>
<tr><td>7</td><td>Infra-red thermometers</td><td>LIT6</td><td>Temperature range 0-260 ^{o}C; Accuracy ± 2%</td></tr>
<tr><td>8</td><td>Standard pots</td><td></td><td></td></tr>
<tr><td>9</td><td>The Standard PM-2.5</td><td>USA</td><td></td></tr>
</table>

	MiniVol™ TAS -AirMetrics		
10	Microbalance Metler-Toledo	Switzerland	Capacity range 0,0001- 6 g
11	*Isoperibol Calorimeter*	Parr 6200	
12	*Dry cabinet*	GMP500	
13	Collect hood		See in detail in the following figure

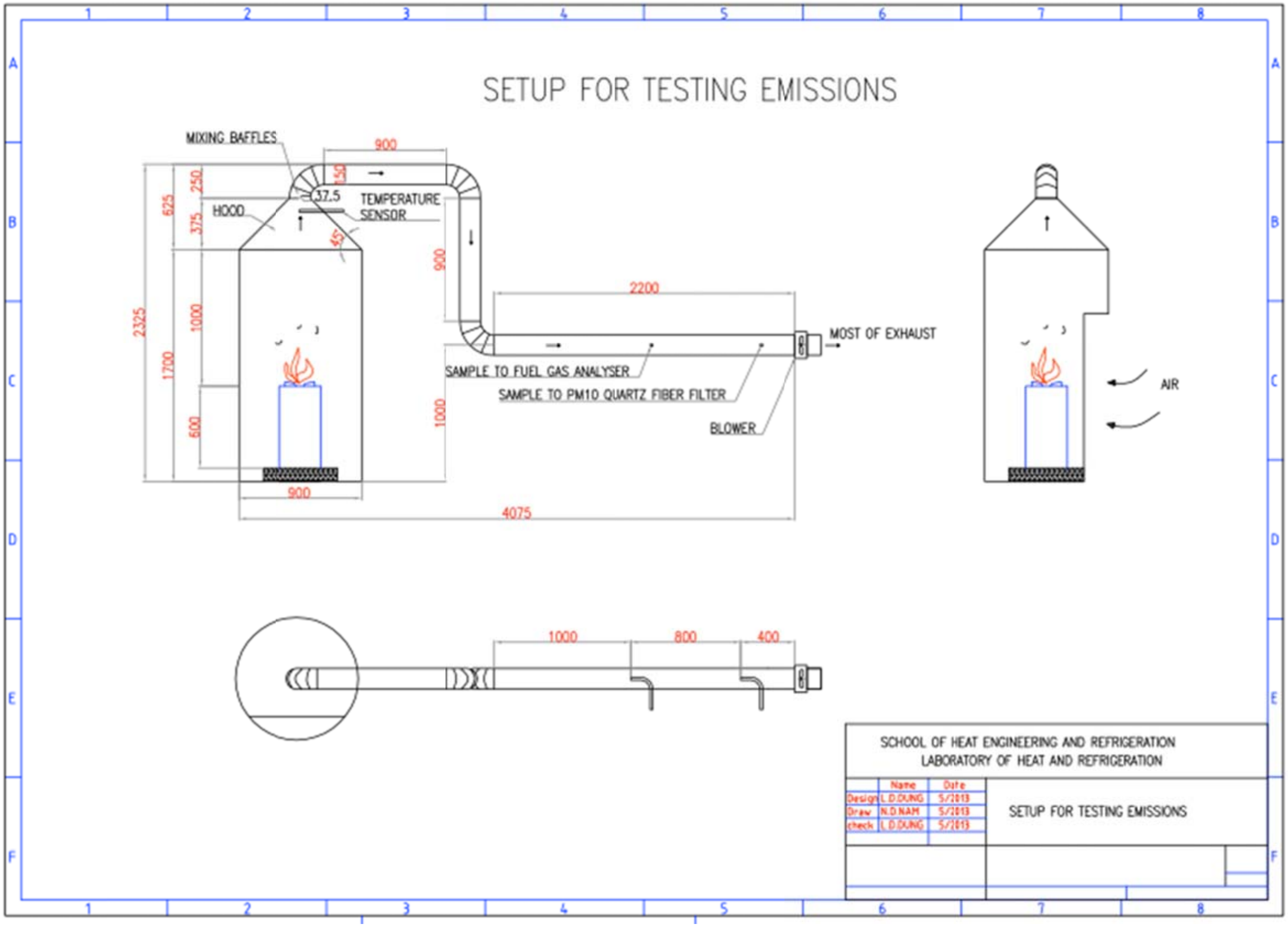

Figure 2b: Diagram of Setup for testing emissions

1.4. Testing procedure

All testing parameters and description testing procedure can be seen briefly in Table 3.

Table 3: Testing parameters

No.	Testing parameters	Brief Descriptions testing procedures	Expected output (Unit)
1	Fuel properties		
1.1	Total fuel fed into the gasifier (per batch)	Weigh all fuel for one batch of each gasifier	(kg)
1.2	Moisture content of fuel	- Drying sample completely in the oven at 107 ^{O}C - A representative sample of about 100 grams is taken, weighed, then dried in an oven at boiling temperature for at least 24 hours, until the weight stops decreasing because the rice husk is fully dry. % Moisture (wet basis) = $(Mass_{Wet}$-$Mass_{Dry)}/Mass_{Wet}$	Moiture content (%)
1.3	Calorific value of fuel	Measuring HHV by a Parr 6200 Calorimeter - Samples will be selected are rice husk and char	HHV (kJ/kg)
2	Efficiency and fuel consumption	The Water Boiling Test (WBT) —The goal is to compare stoves performing a standard task, to see which can most effectively combust the fuel and transfer the heat into the cooking vessel.	

2.1	Thermal efficiency at the burner in case of full power and low power	The WBT is intended to measure stove performance under standardized laboratory conditions: - High (boiling) and Low (simmering) power Stove body starting Cold - Standard amount of water in standard testing pot: 2.5 l - Quantities of time, fuel use, and water evaporated are measured - Every stove is carefully tended to ensure it is operating at its best – all stoves given *equal chance to do well*. *WBT Procedure* —Bring 2,5 l to boil with stove body starting cold —Continue into simmer for 30 minutes at around 5 degrees below boiling —Between each phase, we measure and record: • Time • Mass of fuel • Mass of water in pot • Mass of charcoal remaining • Thermal efficiency are calculated.	(%)
2.2	Fuel consumption at full power	Weigh the bundle of fuel and record time during full power run.	(g/min)

2.3	Fuel consumption at low power	Weigh the bundle of fuel and record time during low power run.	(g/min)
2.4	Time for starting up	Measure time for kindling when stove is in stable operation	(min.)
2.5	Time for boiling 2,5 l water at full power	- Adjust fan speed at full power, - Record the time at which the water in the pot first reaches the local boiling temperature. Record this temperature also.	(min.)
2.6	Burning time (at minimum speed of fan)	- Adjust fan speed at low power, - Record the time	(min.)
2.7	Burning time (at full speed of fan)	- Adjust fan speed at full power, - Record the time	(min.)
3	Emission	—"Collection Hood" – It may measure emissions in 3 different phases of the gasifer operation as starting up, stable operation and shutting down. This is done by knowing both the concentration and flow rate exiting the collection hood.	
3.1	CO	- The hood was designed to colect all gas from stove combustion (see Fig. Setup for testing emissions below this table) - Measurement of flow through exhaust - Sample flue gas to *Flue Gas Analyzer*	(mg/m^3)
3.2	CO_2		(mg/m^3)
3.3	NO_x		(mg/m^3)
3.4	SO_2		(mg/m^3)
3.5	PM2,5	- PM concentration	(mg/m^3)

4	Temperature vs Safety	Differences in temperature between the human body and the cookstove cause heat transfer. Burns occur when more heat is put into the skin than can be dissipated in a given time frame. These rates of heat transfer causing burns correspond to differences in temperature between the stove and body, stove material properties, and the contact area. Factors such as large temperature differences, high material heat conductivity, and large contact areas produce burns more quickly and severely through higher heat transfer rates.	
4.1	Max flame temp.	- Measure flame temperature at full power of fan - This measurement is perform after stove stable operation each 10 minutes interval.	(^{o}C)
4.2	Max stove body temp.	- Measure flame temperature at full power of fan by *Infra-red thermometers* - Temperature measurements are taken at various points on the external surface of the cookstove. - This measurement is perform after stove stable operation each around 10 minutes interval.	(^{o}C)

Table 4: Number of tests per stove and the calendar for these.

	Rua stove (1)	Viet stove (2)	Thuan Phu stove (3)	Traditional stove (4)	SPIN stove (5)
Day 1 (29/5)	2 CST 2 (CST+SM) 4 CO	2 CST 2 (CST+SM) 4 CO 1PM2.5	-	-	
Day 2 (30/5)	-	-	1 CST 2 (CST+SM) 3 CO		
Day 3 (31/5)	1 CST 1 (CST+SM) 2 CO 1 PM2.5	1 (CST+SM) 1 CO 1 PM2.5 1 Base PM	1 CST 1 (CST+SM) 2 CO 1 PM2.5	1 CST 2 (CST+SM) 3 CO 1PM	1(CST+SM) 1 CO 1 PM
Day 4 (1/6)		1 (CST+SM) 1CO 1 PM 01 Base PM	1 CS 1 CO (bếp tắt)	1 (CST+SM) 1 CO 1 PM	2 CST 2(CST+SM) 4 CO 1 PM
Total 4 days	3 CST runs 3 (CST+SM) runs 6 CO 1 PM2.5	2 CST runs 4 (CST+SM) runs 6 CO 2 PM2.5 2 base PM2.5	3 CST runs 3 (CST+SM) runs 6 CO 1 PM2.5	1 CST runs 3 (CST+SM) runs 2 PM2.5	2 CST runs 3 (CST+SM) runs 2 PM 2.5

Where: CST= cold start, SM= simmering

1.4.1. Total fuel fed into gasifier

Because Rua, Viet, and SPIN stoves were batch-TLUD, the fuel fed into gasifier was measured per batch. By measuring the stove weight without fuel (m_s) and the weight of stove with fully-fed fuel (m_{s+f}), the total fuel weight per batch (m_f) was calculated as:

$$m_f = m_{s+f} - m_s \text{ (g)}$$

The Thuan Phu stove has quite large fuel tank, therefore by measuring the fuel bag before and after loading fuel into the tank, the total loaded fuel into the gasifier was calculated. A similar method was applied for the Traditional stove because it is a continuous one. The loaded fuel into the traditional stove was measured by weighing the fuel bag before and after loading fuel into the stove.

1.4.2. Fuel moisture content

Moisture content was analyzed for fresh rice husk (before testing rice husk) and remains of rice husk (after gasification process).

Because fresh rice husk was taken from different fuel bag (for different gasifier), its moisture content was analyzed for each fuel bag.

Three samples of each bag were sampled for moisture content analysis. Samples were taken and stored in different closed bags and remarked for later analysis. The sample analyses were carried out right after the lab testing days. All measurements were conducted by one engineer to ensure consistent results.

The samples were analyzed by drying in the oven at 107 ^{o}C until the weight stops decreasing as mention in the table 3.

1.4.3. Fuel calorific value

Calorific values were analyzed for (1) fresh rice husk (dry base), (2) char, and (3) mixture of char and rice husk after testing by Isoperibol Calorimeter. After single cold start phases or mixing of cold start and simmering phases, char and remain rice husk in the gasifier reactor was separated. In case char can be easily separated from husk, its samples will be taken for calorific value measurement. In other cases, a mixture of husk and char will be measured to distinguish the amount of each part (char, husk) in the mixture after the test.

1.4.4. Thermal efficiency

The WBT 4.2.2 protocol was applied in these tests. The procedures for batch-stove were used. However, some modifications were made due to the fact that WBT 4.2.2 is not totally relevant to batch-type TLUD gasifier.

The following modifications were made:

Because some TLUDs (Viet, Rua, SPIN) can only burn for about 40 mins at full power, the simmering phase was kept for 30 minute-long while a 3,5 l pot (loading 2.5 l of water) was used. The trial tests showed that these gasifiers can bring 2.5 l of water to boil and keep the water simmered for enough 30 minutes. Although Thuan Phu stove and traditional stove which can be operated for a longer time, its kept the same simmering time as 30 mins for evaluating its performance among 5 stoves.

Due to the fact that the burning time of each gasifier is limited, *only a cold start and simmering phases were conducted*. Hot start have not been done because either the weight of the reactors are light or the heat capacity of metal reactors are quite small. The little heat remained in the reactor is expected to have no significant influence to the gasification process. Therefore, all gasifiers were cooled down by fan for 15 mins before they can be used for a next test.

In case of traditional woody biomass stoves, one can weigh fuel before and even during the cooking time (because it is quickly return it into combustion for simmering without significant influence to the cooking task). Rice husk gasifiers are all batch-type TLUDs, thus one cannot measure fuel remain after the cold start phase and continue the simmer phase without disturbing the gasification process. For these reasons, a cold start phase was performed first, following by a cold start phase again and then simmering phase immediately (with the same amount of loaded fuel, same cook and same operation step during cold start phase).

Regarding to thermal efficiency calculations, it is carried out in two cases, one is the case of first single cold start phase and one is the case mixing of cold start phase and simmering phase.

Though calorific values of chars were measured, the remain energy content of char is not counted in the thermal efficiency calculation in all cases. The reason is that in practice, rice husk char is used as fertilizer, rather than an energy source. It is noted that though the remain char in the reactor is not used, a part of char may be gasified/combusted during the final stage of the gasification (applied for Viet, Rua and SPIN gasifiers). In general, almost all gasifiers (Viet, Rua and SPIN) went successfully through both cold start phase and a simmering phase with a little rice husk left. It means the effect of channeling (direct combustion of char) was not significant. In the case of Thuan Phu stove, char was advised to reuse for next operation which can be enhanced thermal efficiency. However, in those tests all cases were performed at the same operation and calculation methods.

In addition, due to the fact that it is difficult to control the flame by forced draft fan of gasifiers, the simmering phase was not performed perfectly. The fan was taken further from the gasifier until the fire is going to stop. However in all cases, the temperature of water stayed quite high (around 97 degree Celsius). These temperatures were also not consistent throughout the tests.

1.4.5. Other procedures

Unloading remained solid from stoves after testing:

In all cases, after testing procedures the remain solid of the stoves (see in Fig. 3) were unloaded and stretched into three parts as black solid, mixing color of solid and rice husk was assumed a char part, a mixing part and a fresh rice husk part, respectively. Their weight were recorded and sampled for moisture content analysis and high heating value measurement.

Full power operation time:

In case of Viet, Rua, SPIN, Thuan Phu stoves, the forced draft fan speed is adjusted at full power during operation and recorded fire out time.

Low power operation time:

In case of Viet, Rua, SPIN, Thuan Phu stoves, the forced draft fan speed is adjusted at low power during operation and recorded fire out time.

Figure 3: Char and remain rice husk separation

2. RESULTS AND DISCUSSIONS

Overall testing results are show in the table 5

2.1. Fuel properties

As we can see in the Table 5, loaded fuel of each test have been analyzed, its moisture contents are range of 9,7 to 11,4 %. In case of gasifier stoves, all rice husk have fed to stove with the same method, its amount is around 1,5 kg per batch except for Thuan Phu stove. It is the biggest fuel container one (around 8,5 kg per batch).

For thermal efficiency calculation, LHV of each sample have been analyzed, it is around 1260 kJ/kg.

Table 5: Testing results

No	Parameter	Unit	Stove (1)	Stove (2)	Stove (3)	Stove (4)	Stove (5)
1	Fuel properties						
1.1	Fuel per batch	g	1567	1478	8500	continuous feeding	1358
1.2	Moisture content of fuel	%	9,99	9,82	9,73	10,72	11,4
1.3	Calorific value of fuel (Dry base) HHV	kJ/kg	15428	15428	15428	15428	15428
1.4	LHV (dry base)	kJ/kg	14108	14108	14108	14108	14108
1.5	LHV (Working base)	kJ/kg	12699	12723	12610	12531	12500
2	Efficiency and Fuel consumption						
2.1	CST *Thermal efficiency* (full power)	%	17,6	19,3	17,5	13,9	20,0
2.2	CST-SM *Thermal efficiency* (low power)	%	18,8	17,1	19,7	14,3	17,5
2.3	Fuel consumption at full power (CST)	g/min	44	48	38	36	44
2.4	Fuel consumption at low power (CST-SM)	g/min	30	33	26,5	33,6	25,3
2.5	Time to start up	min	<2	<1	<4	<2	<3
2.6	Time to boil 2,5 l water at full power	min	9	10	11	15	13
2.7	Burning time (at full speed of fan)	min	35,6	30,8	80	-	30,8
2.8	Burning time (at low speed of fan)	min	47	44	100	-	45
3	Emission						
3.1	CST CO	mg/m^3	418	1581	426	375	956
3.2	CST-SM CO	mg/m^3	206	1883	398	574	1059
3.3	CST-SM PM2,5	mg/m^3	13,1	12	2,5	37,9	9,45
4	Max stove body temperature	^oC	125	325	85	220	75

2.2. Efficiency

2.2.1. Time to start up

Time to start up was measured beginning when rice husk was considered ignited and ending when stove shown stable flame and started setting up the water pot.

It can be seen in Table 6 and Fig.4 The Viet Stove brought stable flame more quickly than any of the other stoves, it is less than 1 minute. In case of Rua stove and traditional stove, it was required less than 2 minute for getting stable flame. It is the most difficult to start up and longest starting up time was considered Thuan phu stove. It was also produced more density smoke during starting up and unloading remain fuel after testing (please see Fig. 5 for more evident).

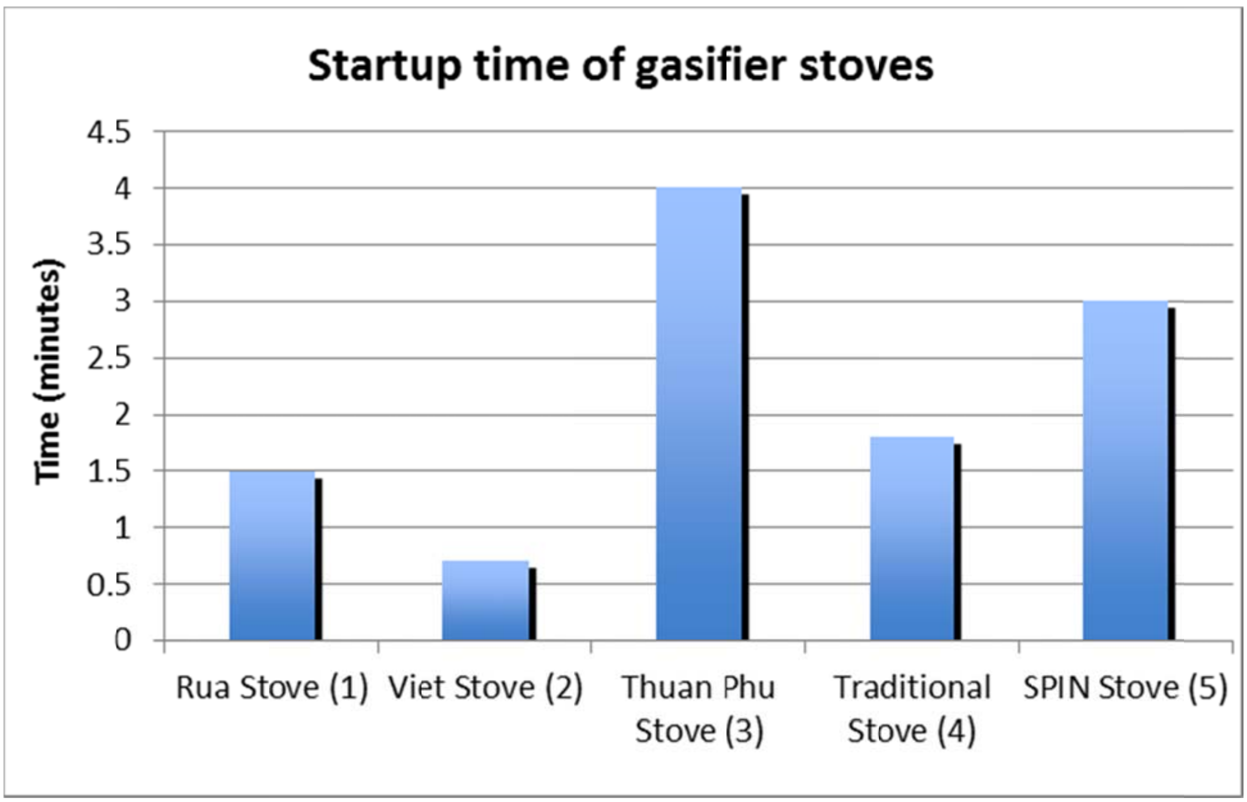

Figure 4. Time to start up for the CST phase

2.2.2. Time to boil

Time to boil was measured beginning when the flame was considered stable and the water pot was started setting up and ending when water started boiling (at local atmospheric pressure) at high power condition (in the cold start phase).

The traditional stove brought water to a boil more slowly than any other gasifier stoves, it took about 15 minutes for starting boiling water. By seeing Fig. 6, among gasifier stoves, the Rua stove brought water to a boil more quickly than any the other one, and then slower order for Viet stove, Thuan Phu stove. The slowest performing stove for water boiling time was SPIN stove, it took about 13 minutes by taking an average.

(a) Thuan Phu stove (3)

(b) Viet stove (2)

(c) Rua stove (1)

(d) Tradditional stove (4)

Figure 5: Starting-up stoves

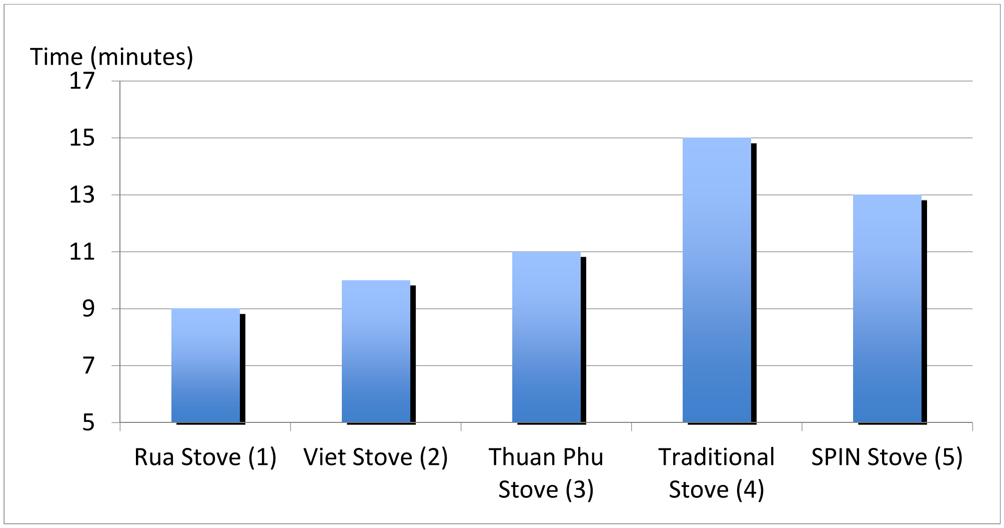

Figure 6. Time to boild 2.5Litre of water

2.2.3. Thermal Efficiency

Thermal efficiency is ratio of the heat content of increasing the water temperature and latent heat of evaporating the mass of water released as steam, to the total energy of rice husk consumption. As we know char still remained energy, but it was considered as not useful energy in the tests and the practical operation because it may be delivered as fertilizer as mention in the section 2.4.4. In order to comparing stove's performances, thermal efficiency have been calculated by the same above mention method for the CST and CST-SM phases. The each final value of thermal efficiency show on the Fig. 7 was averaged from 3 runs.

However in practical application and from energy saving point of view, Thuan Phu stove char is advised to be reused for the next operation time, therefore it may enhance its performance for thermal efficiency.

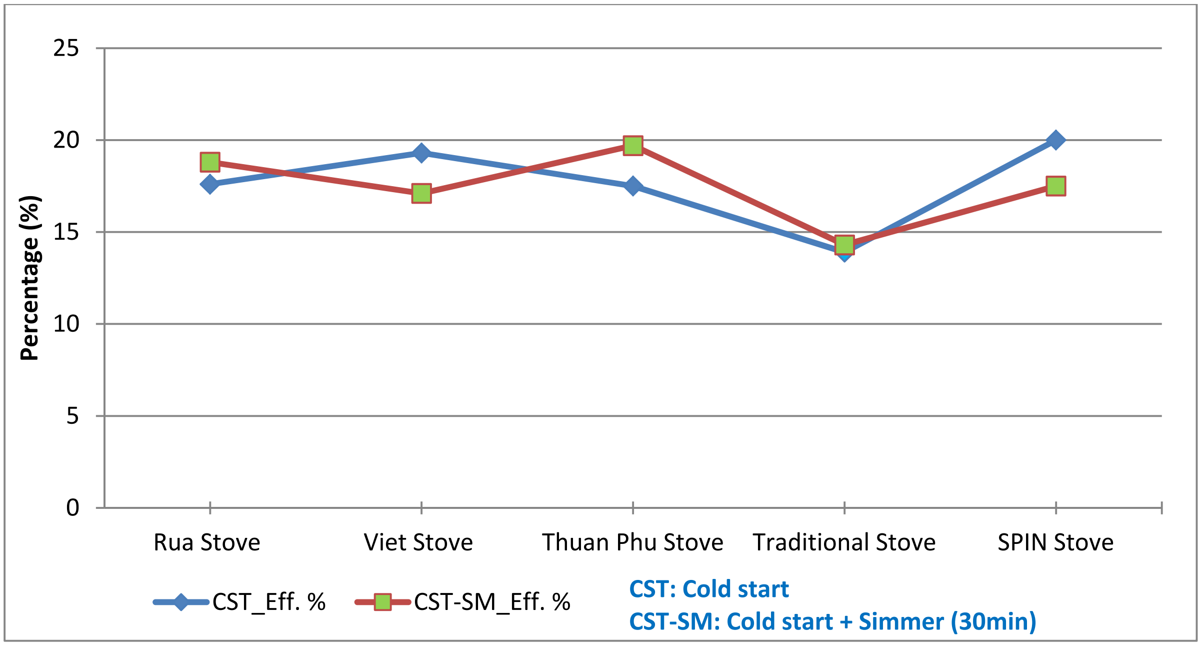

Figure 7. Thermal efficiency of 05 stoves from WBT tests

The gasifier stoves again show better performance within thermal efficiency in both cases of CST and CST-SM. As can be seen, thermal efficiency of gasifier stoves are quite similar, it's range of 17 to 20 %. The lowest performing stove for thermal efficiency as measured by the "WBT" were Traditional stove, its around 14 %.

2.3. CO emissions and PM2.5 emissions

The CO concentration from exhaust gases was measured for 3 minutes during CS and CST-SM intervals. The final value of CO concentration was calculated by averaging all recorded data that shows in Table 5. In order to compare to the actual indoor emission in the kitchen, stack CO concentration [mg/m^3] was converted in to CO emission rate as [g/MJ-del] and [g/min] by dividing total CO emission to total energy delivering to water pot and to total testing time, respectively.

The PM2.5 emission contents were measured by sampling exhaust gases from hood duct during the CST-SM phases, and then each collected PM2.5 dust of the test was weighed by Microbalance Metler-Toledo. The PM2.5 emission concentrations were calculated by dividing each collected dust content to total cubic meter of exhaust gases during the CST-SM Test. For the comparison purpose, PM2.5 concentrations were also converted in to PM2.5 emission rate as [g/MJ-del] and [g/min] as same as CO emission convertion. The detailed emission levels of tested stoves are presented in the Table 7 below.

The graphs show well CO emissions performance belongs to Rua stove, Thuan Phu and Traditional stove in both case of CST and CST-SM, then poor performance SPIN stove and finally worst performing Viet stove. Viet stoves are characterized by high CO emissions, which is evident by their poor performance on the CO emission metrics.

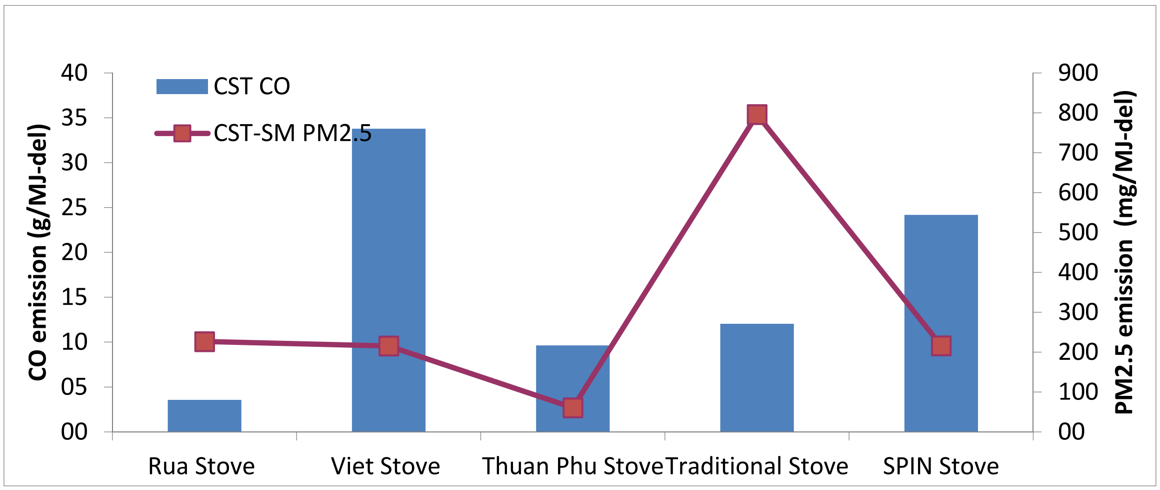

Figure 8. Emissions performance of 5 stoves for the WBT during CST-SM.

PM2.5 emission measurement has been only carried out for CST-SM operation. The data indicate in Figure 3, PM2.5 emission performance of most gasifier stoves are quite good, PM2.5 emission contents are lower than 230 mg/MJ-del, especially Thuan Phu stove was the best PM2.5 emission performance its content is only about 60 mg/MJ-del. It can be explained by seeing sysgas pass way to burner of Thuan Phu Stove. Syngas rises up through rice husk layer, then goes to plastic pipeline and finally passes through water pipeline before rises up the burner, therefore, almost particle mater and tar is absorbed by rice husk layer and water. The worst PM2.5 performance is traditional stove, PM2.5 emission content is nearly 800 mg/MJ-del.

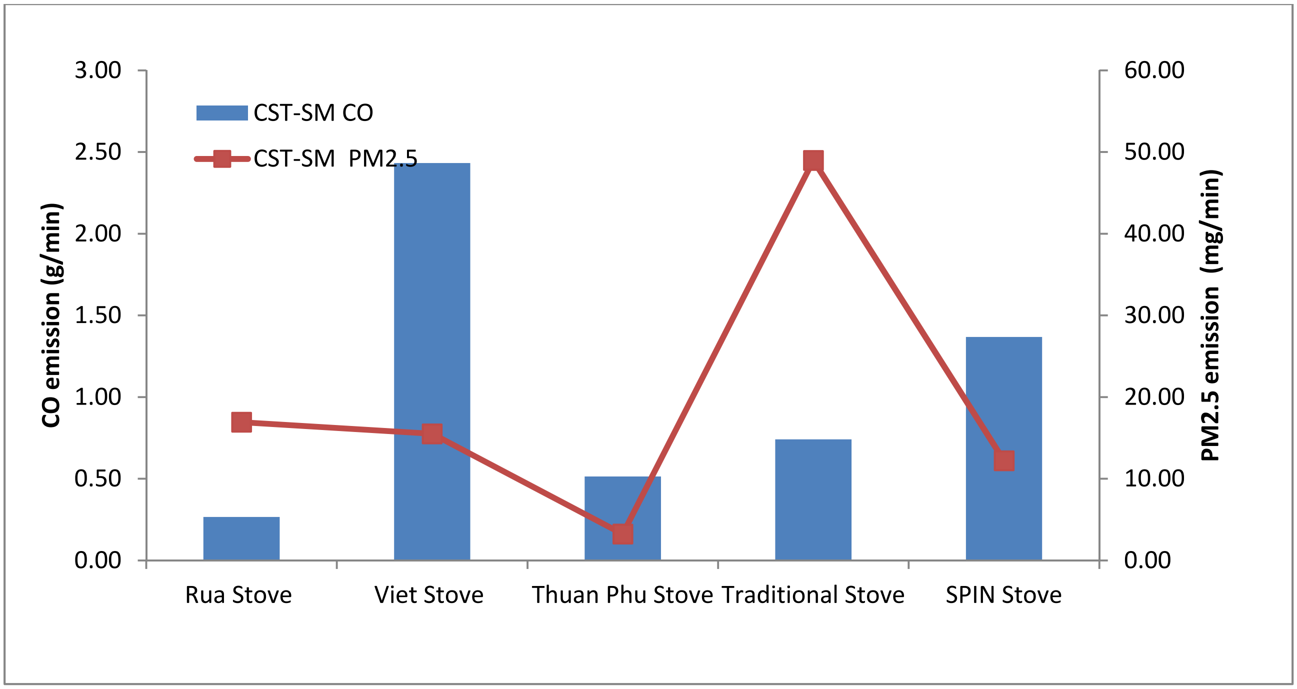

Figure 9. Emissions performance of 5 stoves the WBT during CST-SM

By observing both PM and CO emission levels in Fig. 8 and Fig. 9, the greatest challenge for achieving the highest levels of performance will be reducing PM and CO emissions, especially to approach those achieved by Thuan Phu stove and Rua stove. Also evident in the Figures is the large range of emissions performance for the stoves. This variability is likely due to differences in operation, design differences, and testing conditions.

<u>Emisson factors:</u>

One of the common indicator to compare stove emission is the emission factor which measure the amount of CO/PM emitted per 1kg of fuel burnt. The Figure 10 shows the emission factors of different tested stoves

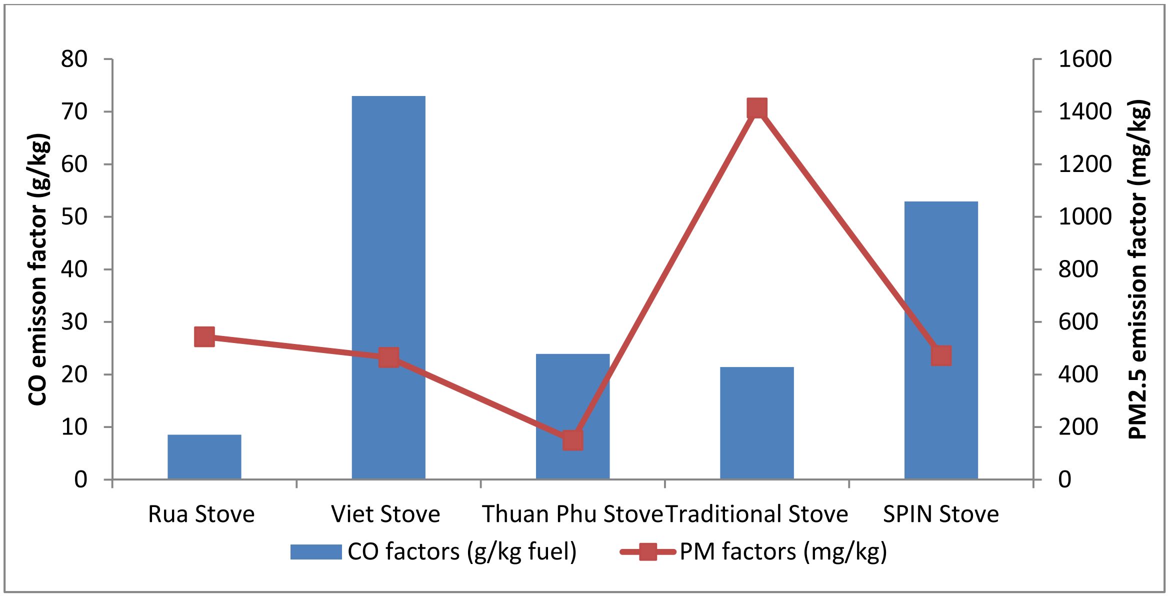

Figure 10. Comparison of emission factors (EF)

To have better understanding on the CO emission factor of the stove, it can be refered to other published data from Approvecho[1] on 3Stone Fire stove, and VITA stove which have a CO emission factor of 40g/kg and 90g/kg respectively.

Emission for cooking task:

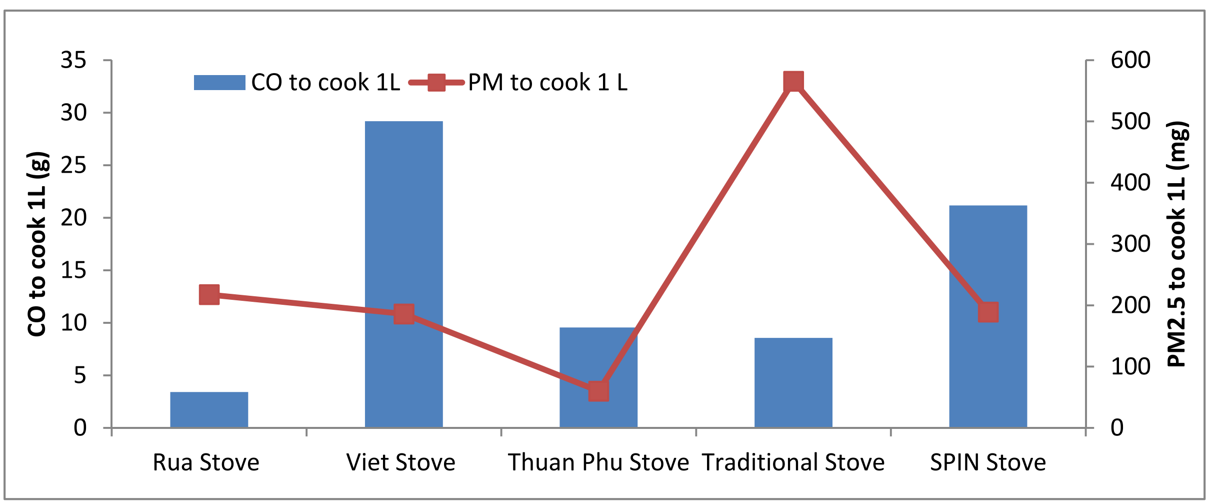

Figure 11. Relation of CO and PM for a cooking task under the emissions hood

In order to compare with international stove standards, a reference of the CO emission data serices is presented in the figure 12 below. The data was extracted from the Test Results of the Approvecho Centre.

[1] Test Results of Cook Stove Performance, PCIA, Approvecho Centre. http://www.pciaonline.org/files/Test-Results-Cookstove-Performance.pdf

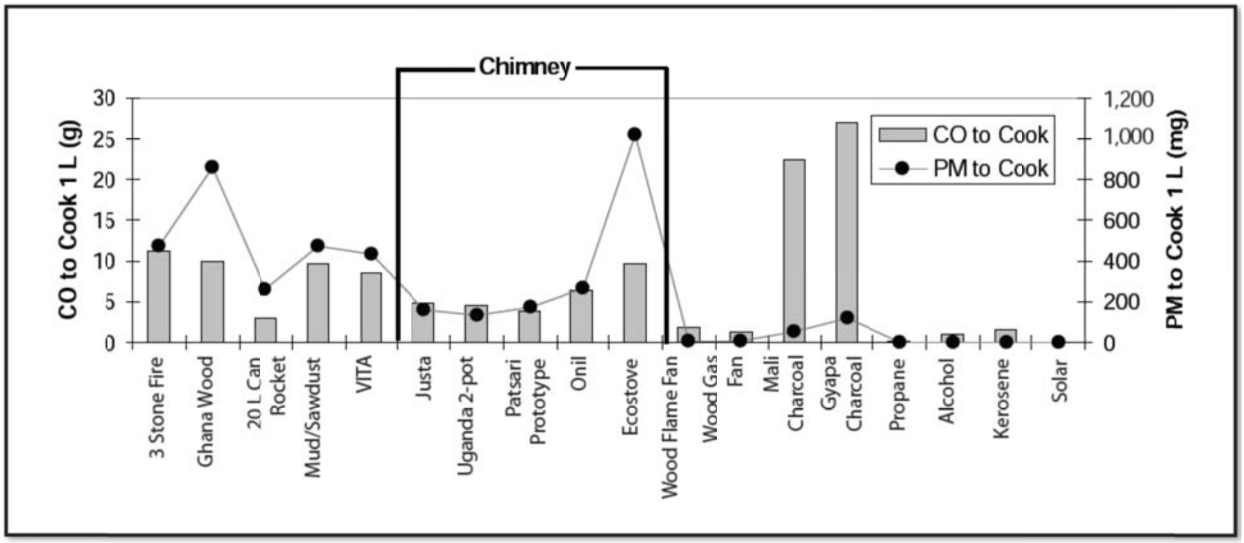

Figure 12. Relation of CO and PM for a cooking task under the emissions collection hood

It can be seen that, Viet stove has the highest CO emission factor compared to other tested stoves. The testing results can be able to used in international standard.

3. CONCLUSION

In regards to efficiency, time to boil, CO emissions and PM2.5 emissions, time to boil all stoves offered improvement over the traditional stove.

Although, thermal efficiency of SPIN stove is slightly higher than that of the other gasifier ones for CST phase, CO emission rates are still high. The lowest performing stove for CO emissions as measured by the "WBT" was Viet stove.

Overall, in terms of both CO emissions and PM2.5 emissions, the Rua stove and Thuan Phu stove performed the best.

In terms of time to start up and time to boil, Viet Stove and Rua stove performed the best.

In term of PM2.5 emissions, The Thuan Phu stove had the lowest emission, the other gasifier ones had the same PM2.5 emission level.

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