# Sized multi-fuel horizontal clean continuous combustion device (SM-HCCD)

## Development – time summary
## April 2014 to 02 Feb 2016

H. S. Mukunda

Based on requests for sand drier from Sameer Kanabargi, Belgaum, the development of a horizontal combustion device was pursued in October 2014. The combustion behavior appeared smooth and clean unobserved with other modes.

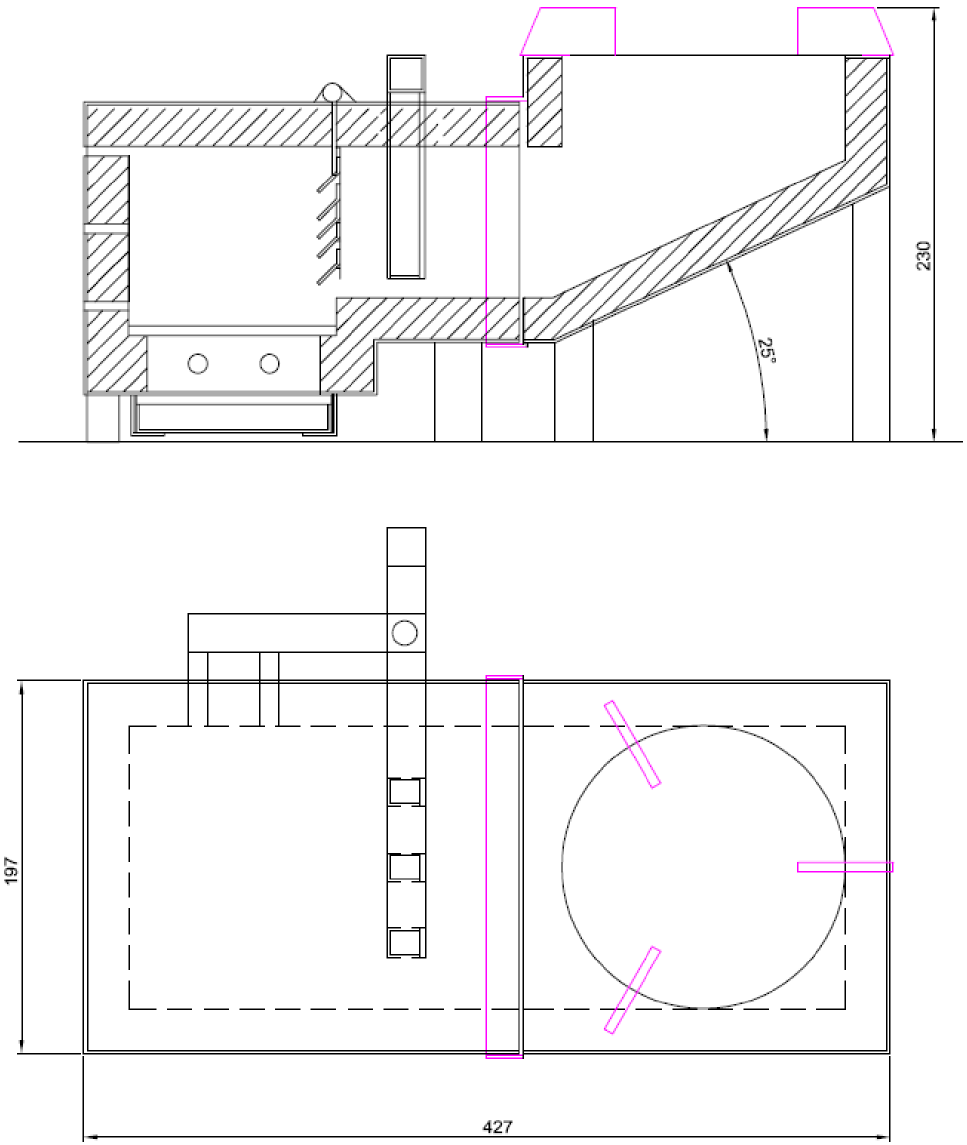
The position of the air supply system was transferred to an upstream zone to reduce the heating of the wolf blower supplying air to the system. The air supply was about  50 g/s (3000 lit/min) for a combustion rate of  40 kg/h.

It was briefly tested in a oil heating system. Full integration was not possible because the internals of the system did not permit changes to be done.

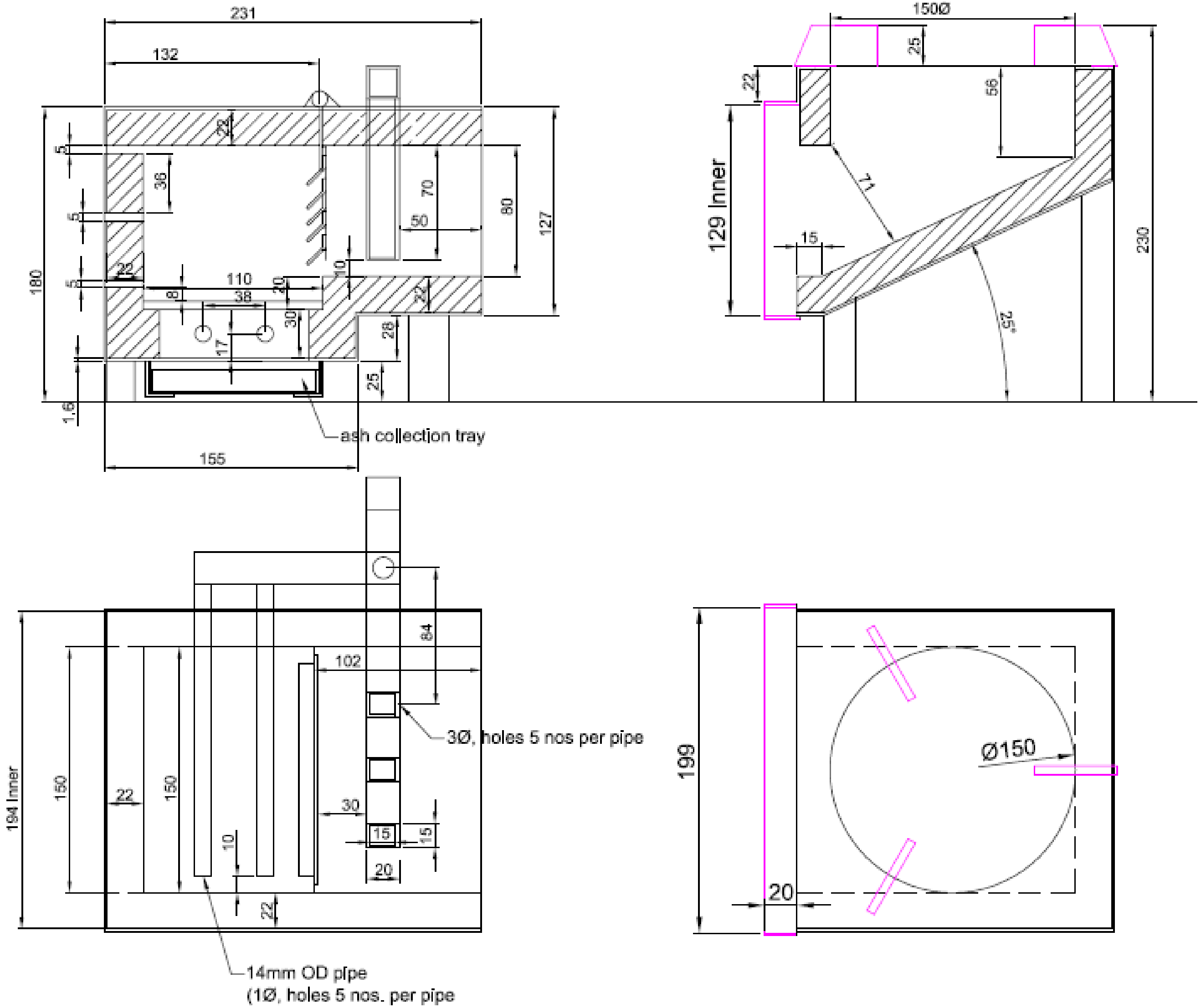
System operating with chipped fuel and pellets

Measurements of gas temperature – 1150 to 1200 C
Run initially on wood chips at 30 kg/h and then with pellets
When it reached 53 kg/h for half an hour. At this time
the bottom grate rods melted.

# Single pan stove
# 1 to 1.5 kg/h system

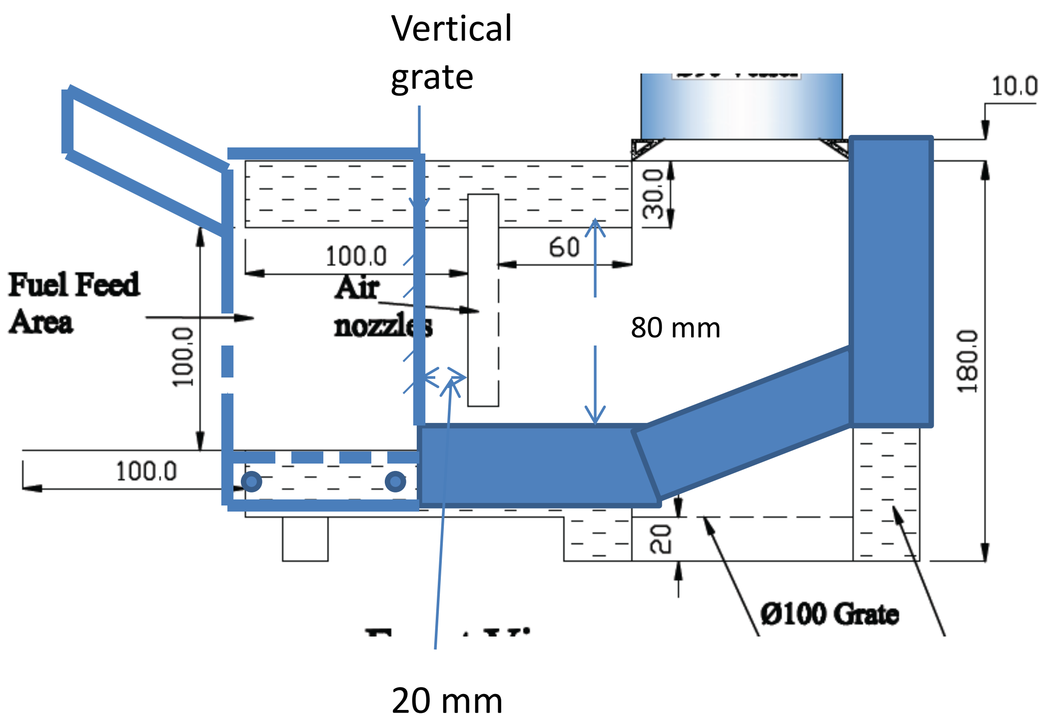



Single pan system combustion system – 8 July 2015 – split and Assembled parts;

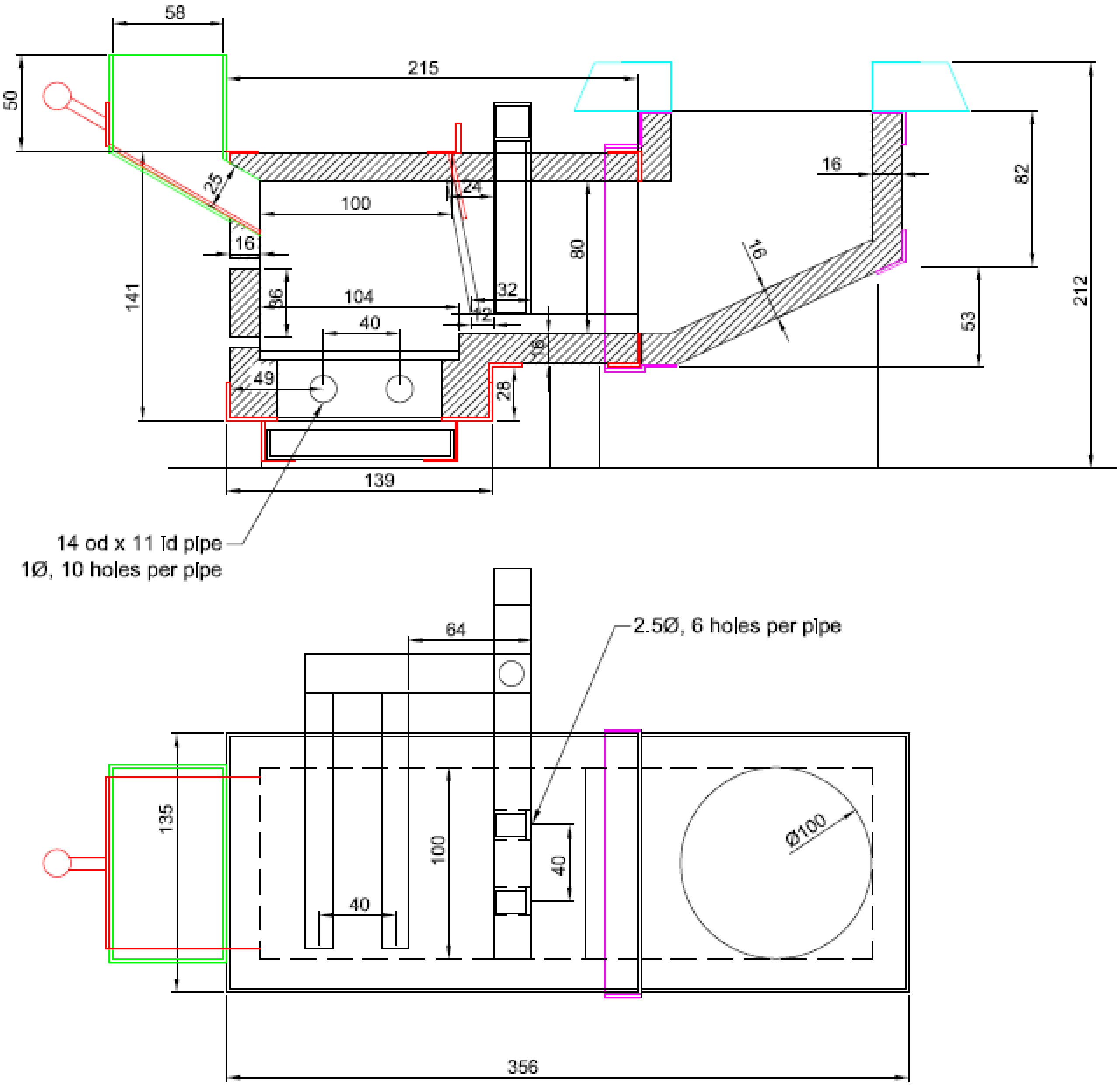



Details of the split-assembled design (8th July 2015)–
Tested and further modifications made.

Changes from the original drawing above.
The internal cross section should be 100 mm wide x 80 mm (high). The separation between the air supply struts and the vertical grate should be about 20 mm and not more. The air supply pipe to the bottom zone should be 15 mm od and 12 mm id, The air flow should be more into this region. You can make the number of 1 mm holes to 20 instead of 10 at present.
The whole stove is still heavy. The efficiency is about 30 %. This must be brought up to 40 %. The inert weight has to be brought down. Use a thin MS 1.2 mm sheet based inner envolope and surround that aluminosilcate insulation of 25 mm thickness and bind it with think metal strips. Only the fuel chamber top can be made as you have done. You anyway have a think green painted Outer cover. This also can be made of 1.2 mm perforated sheet.



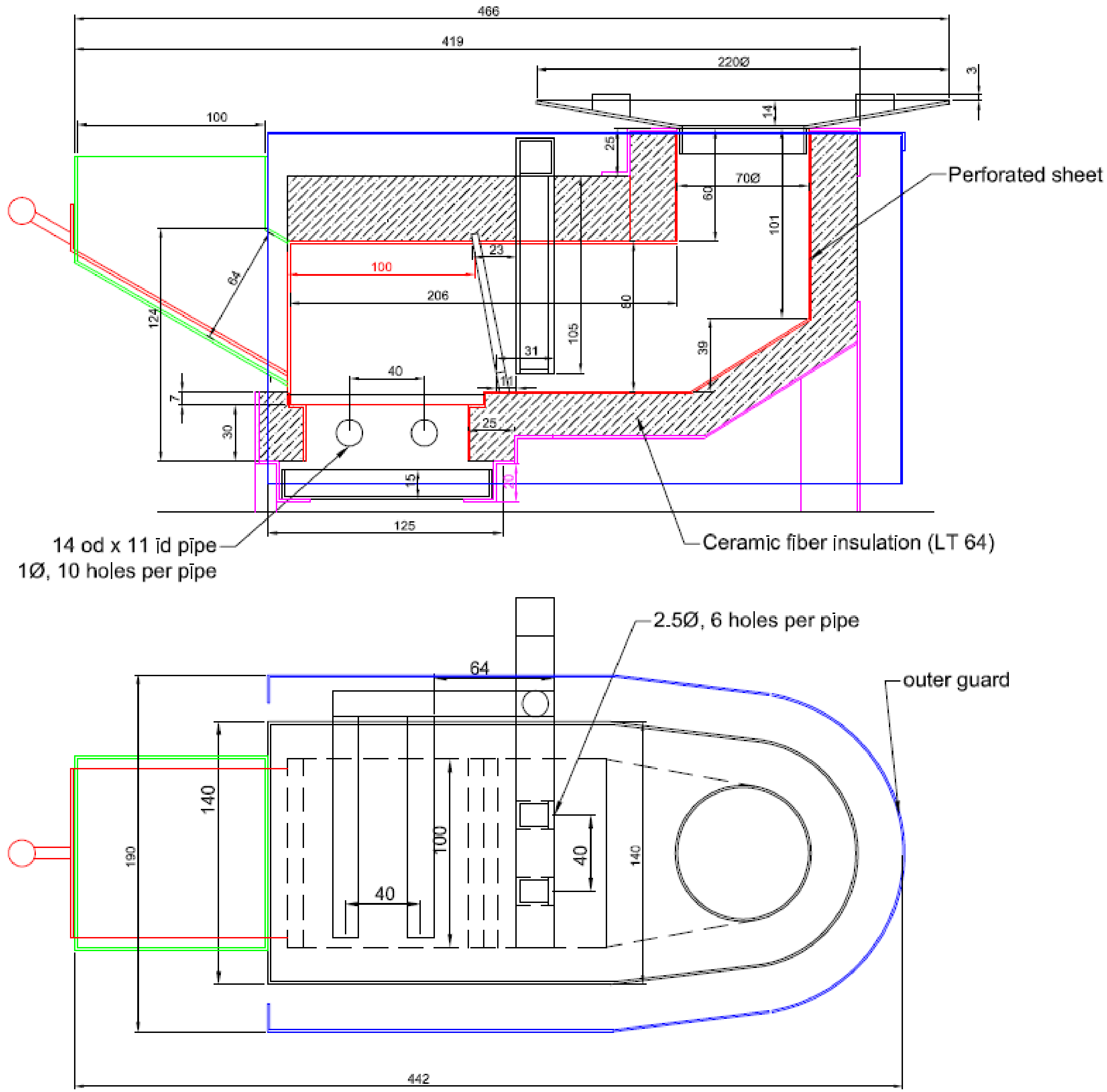

The air nozzles should also be made of 1 mm sheet, the holes should be 2.5 mm x 6 numbers over two struts. Thus there will be only 12 holes of 2.5 mm dia. The battery should be operated at 12 V and then the stove will function very well with high efficiency and low Inert weight and perhaps cost as well.




**Single pan stove design – 27 August 2015**

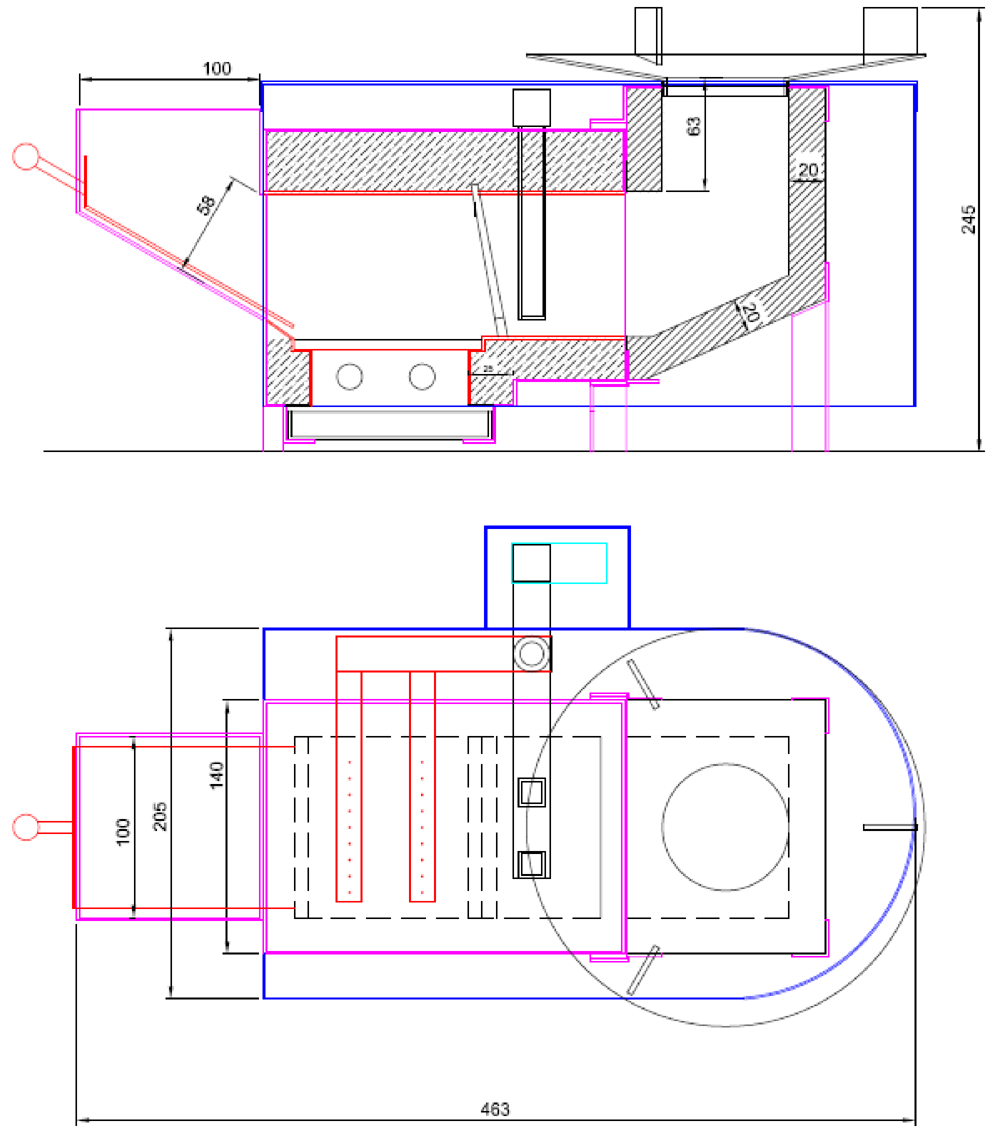
Notice the lateral air supply slots at the left;

They were found problematic



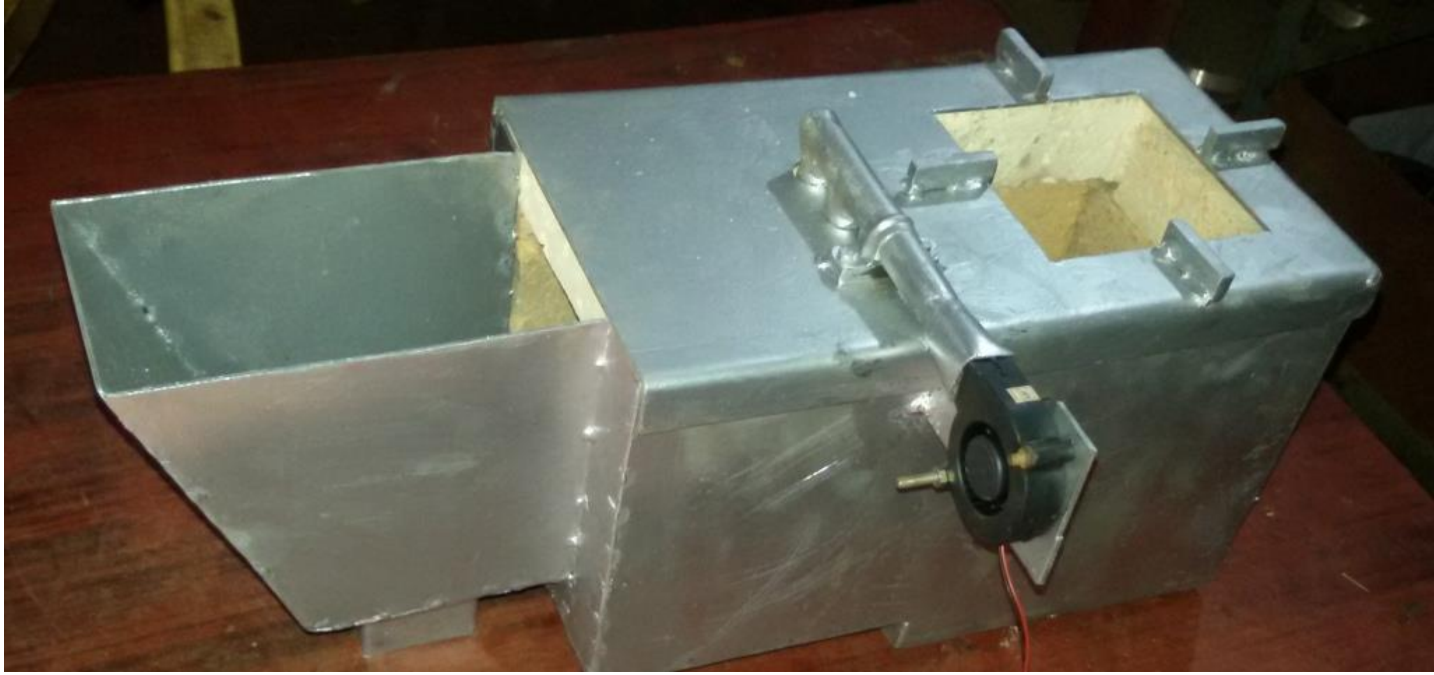

Design 12 August 2015 – Notice the changed fuel feed arrangement

Design 12 Sep 2015

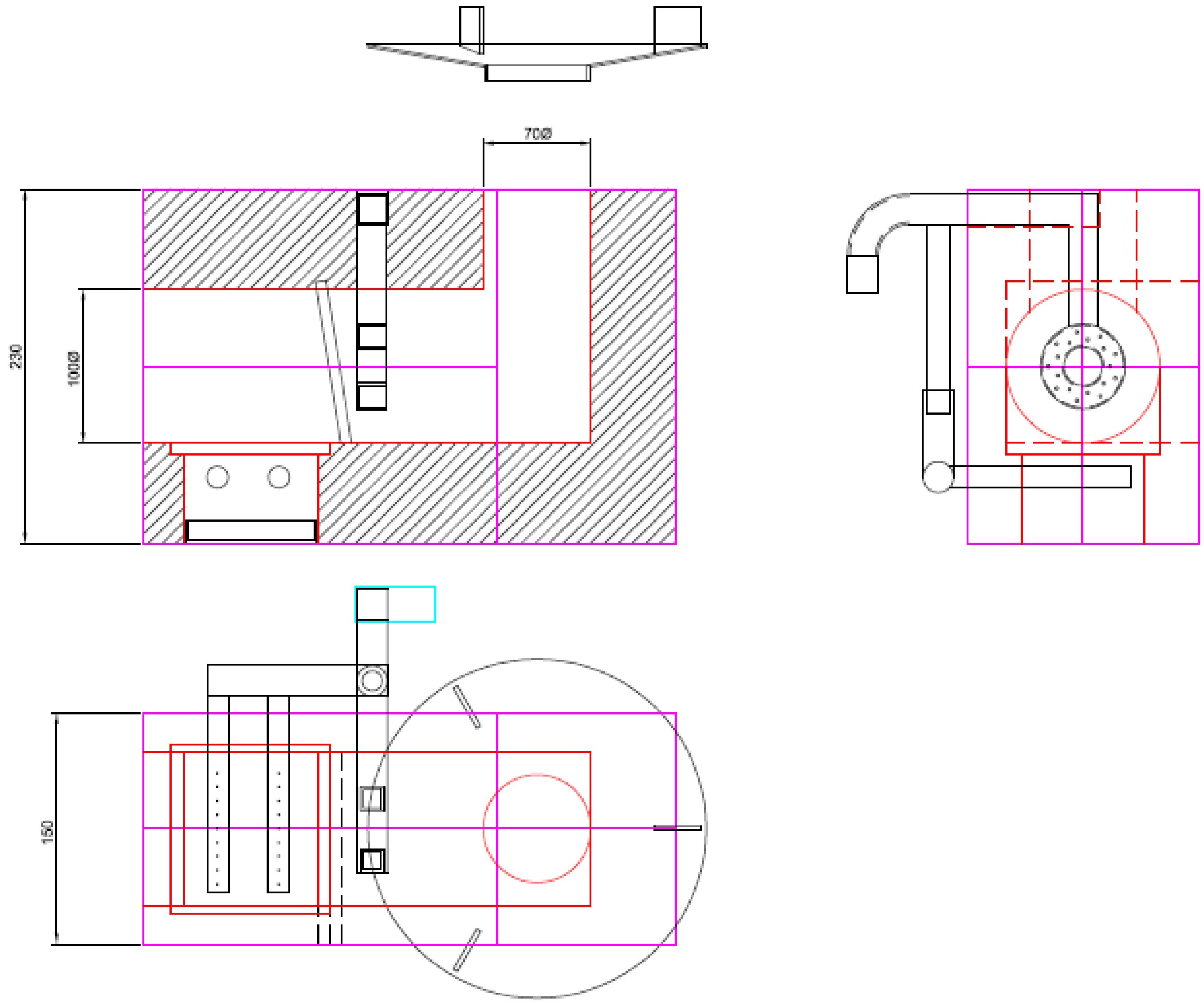



1 kgph ASSEMBLY 12-9-2015

Early HFI based System design. Abandoned because of weight



The bottom one with foam concrete Abandoned because it fractured after three tests

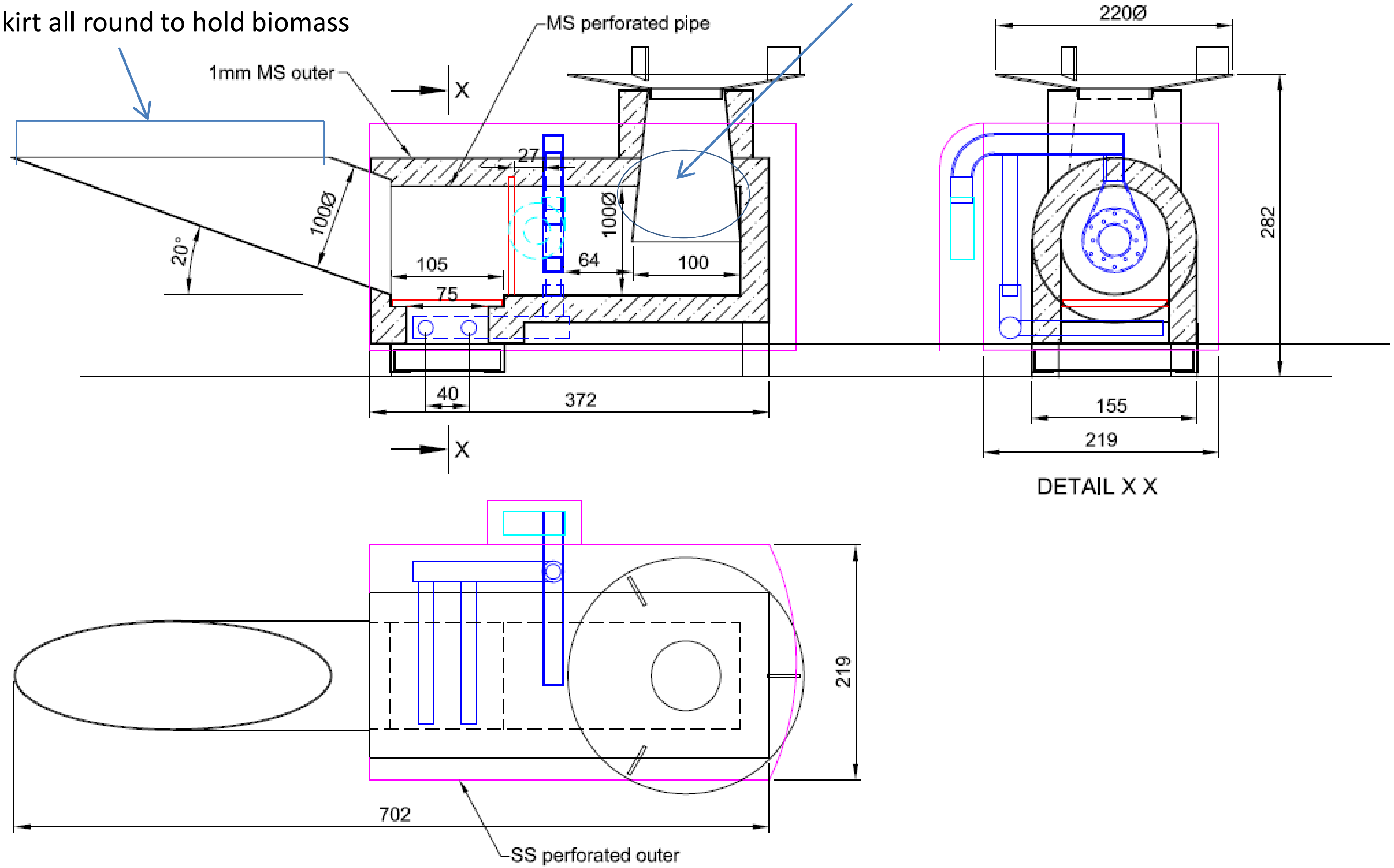



1 kgph BRICK CONSTRUCTION 23-9-2015

Design – too heavy and absorbs most heat
Uses circular air injection system

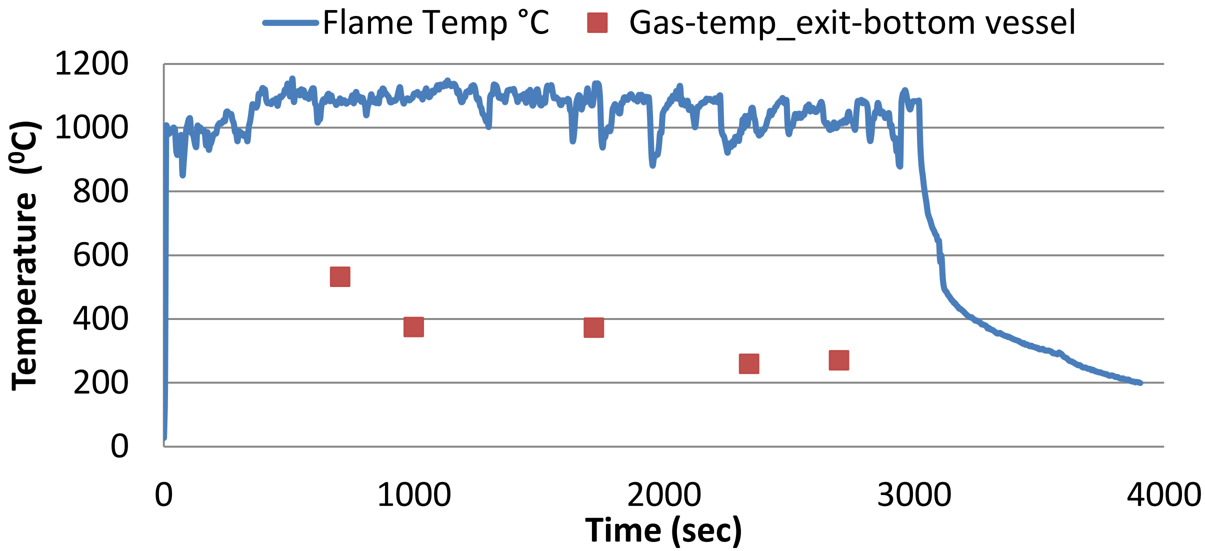
The cone should end at the level of the
Beginning of the insulation, please.

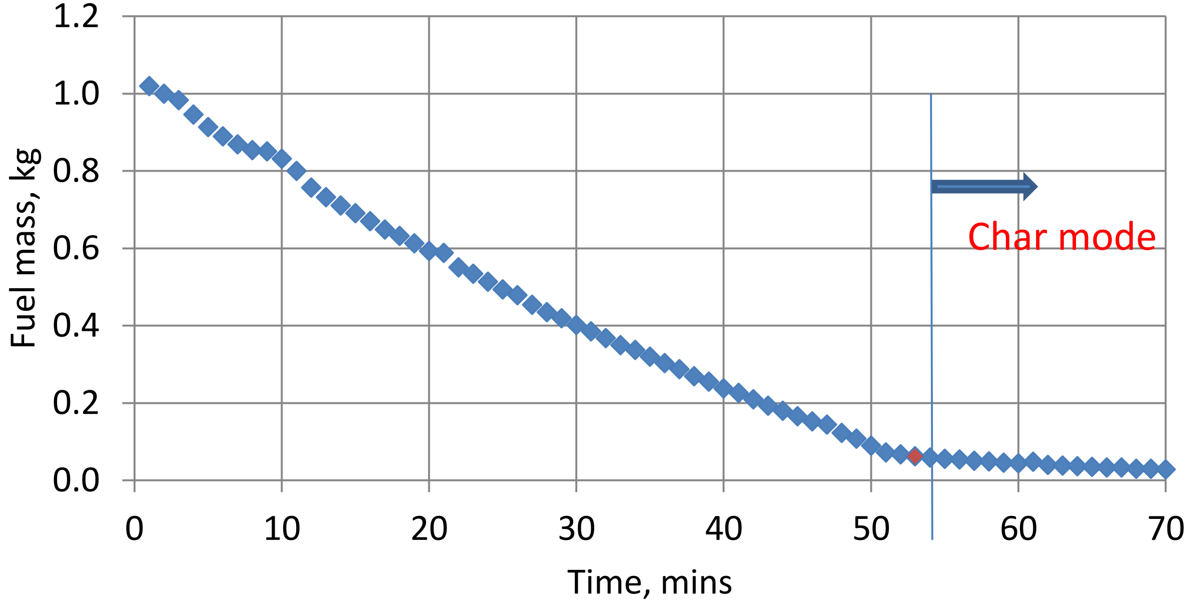
Perforated sheet
skirt all round to hold biomass




Aravindakshan – please note two modifications.

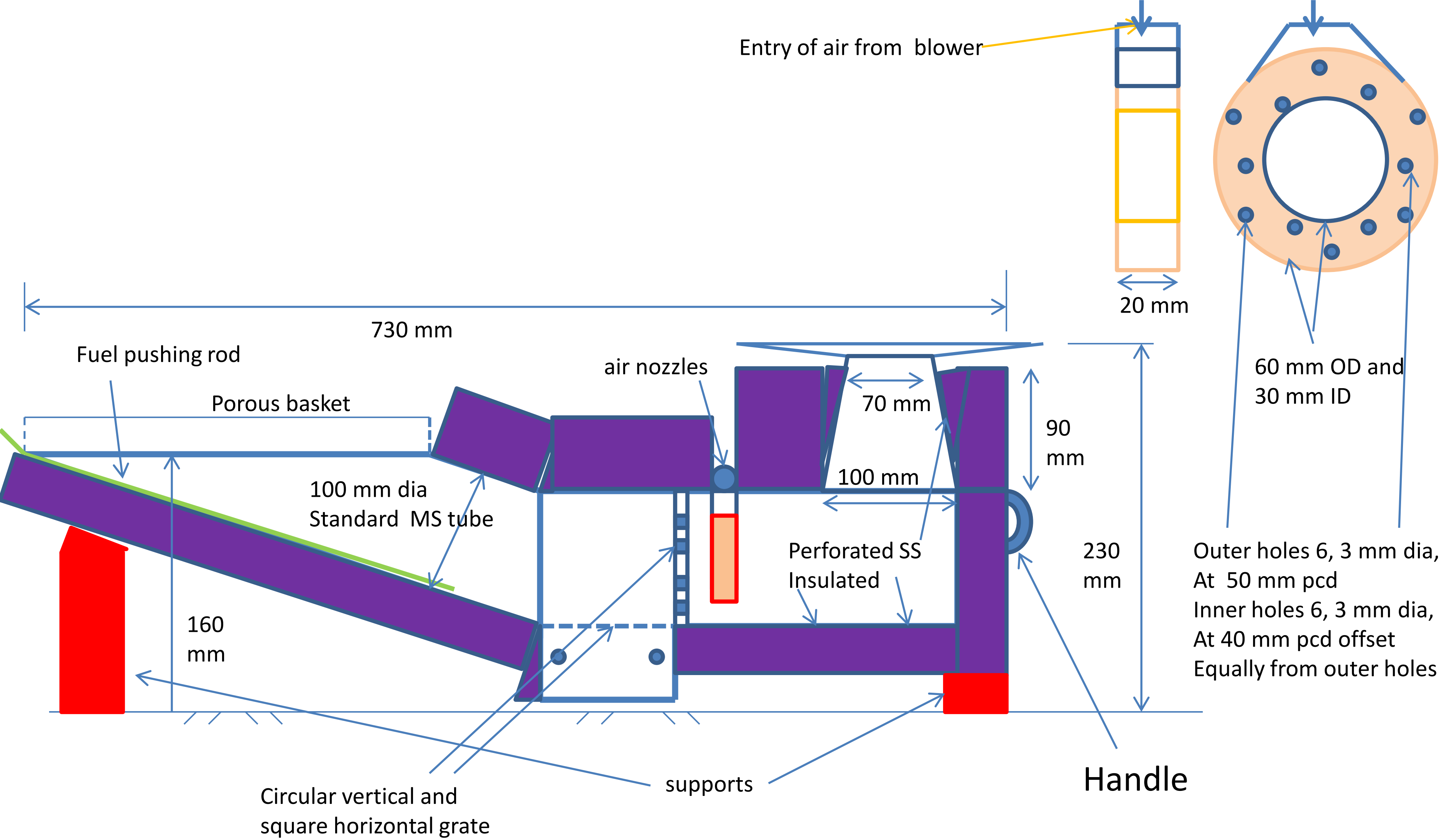

The early single pan stove with Al vessel + water being
Tested for efficiency and emissions at CDM, JU;
Notice AGNI-SAKHI as its name




The high uniform temperature between 900 and 1100 C, largely around 1050 C and near uniform combustion process are the prime indications for good performance

Single pan stove with perforated
SS outer sheathing and a pressure
cooker on a kitchen table




# Circular tube based single pot HC$^3$D design
# Low cost option

Circular tube based design for the stove with a Perforated SS covering for aesthetics and maintaining a temperature of not more than 50 C on the outside

# Two-pan stove

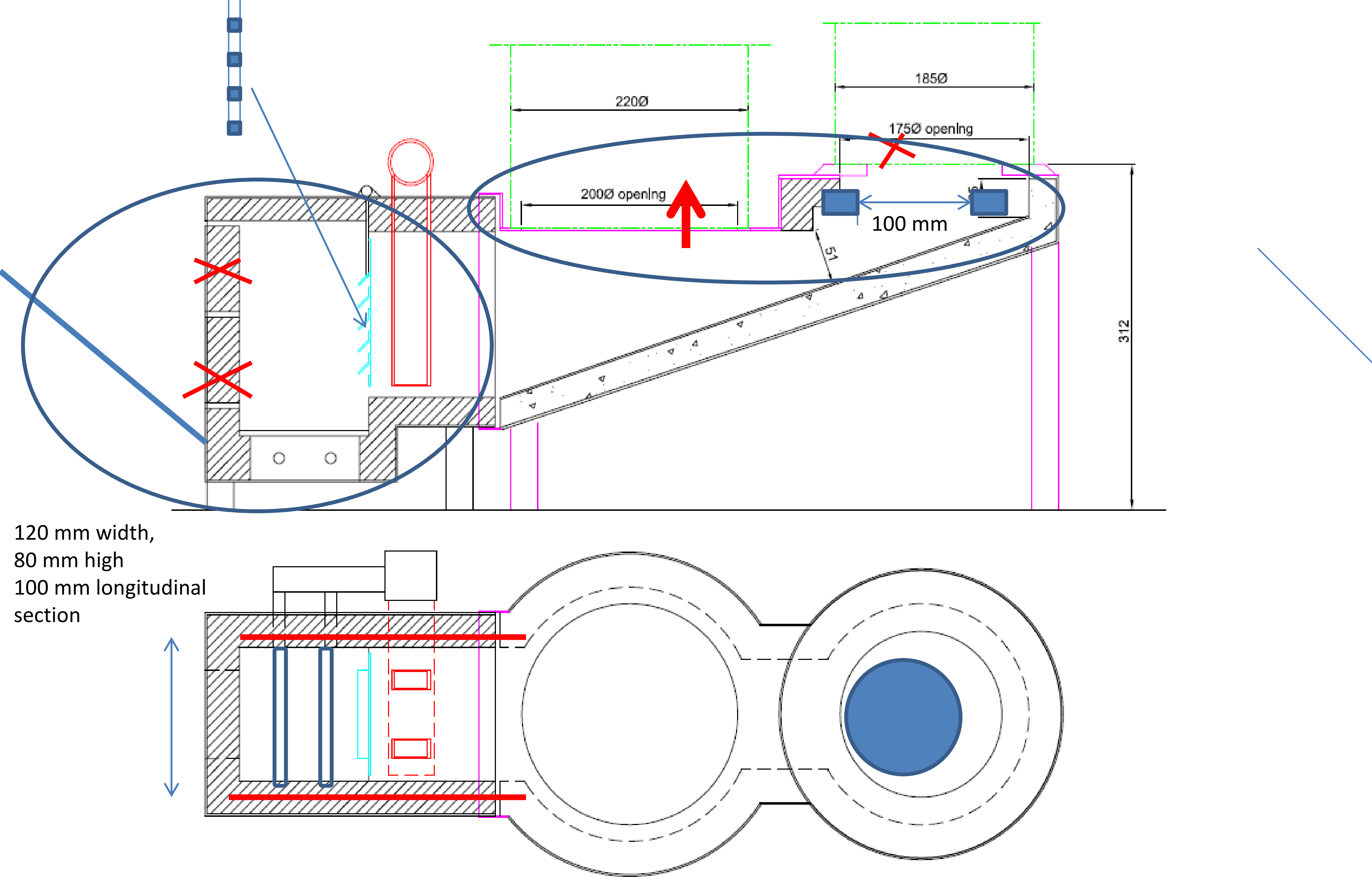
After this unusual desirable combustion behavior was noticed, subsequent efforts were focused on 1 – 1.5 kg/h and 2 to 5 kg/h systems.

A further background to this is the EIGAS system design that worked very well with fire-wood class of fuels and large systems up to 120 kg/h were built and yet small systems of the same design had not shown this class of clean combustion behavior.

Rich combustion in EIGAS was invariably sooty but in the horizontal system, it was non-sooty and had perhaps higher alcohols yet to be completely burnt.

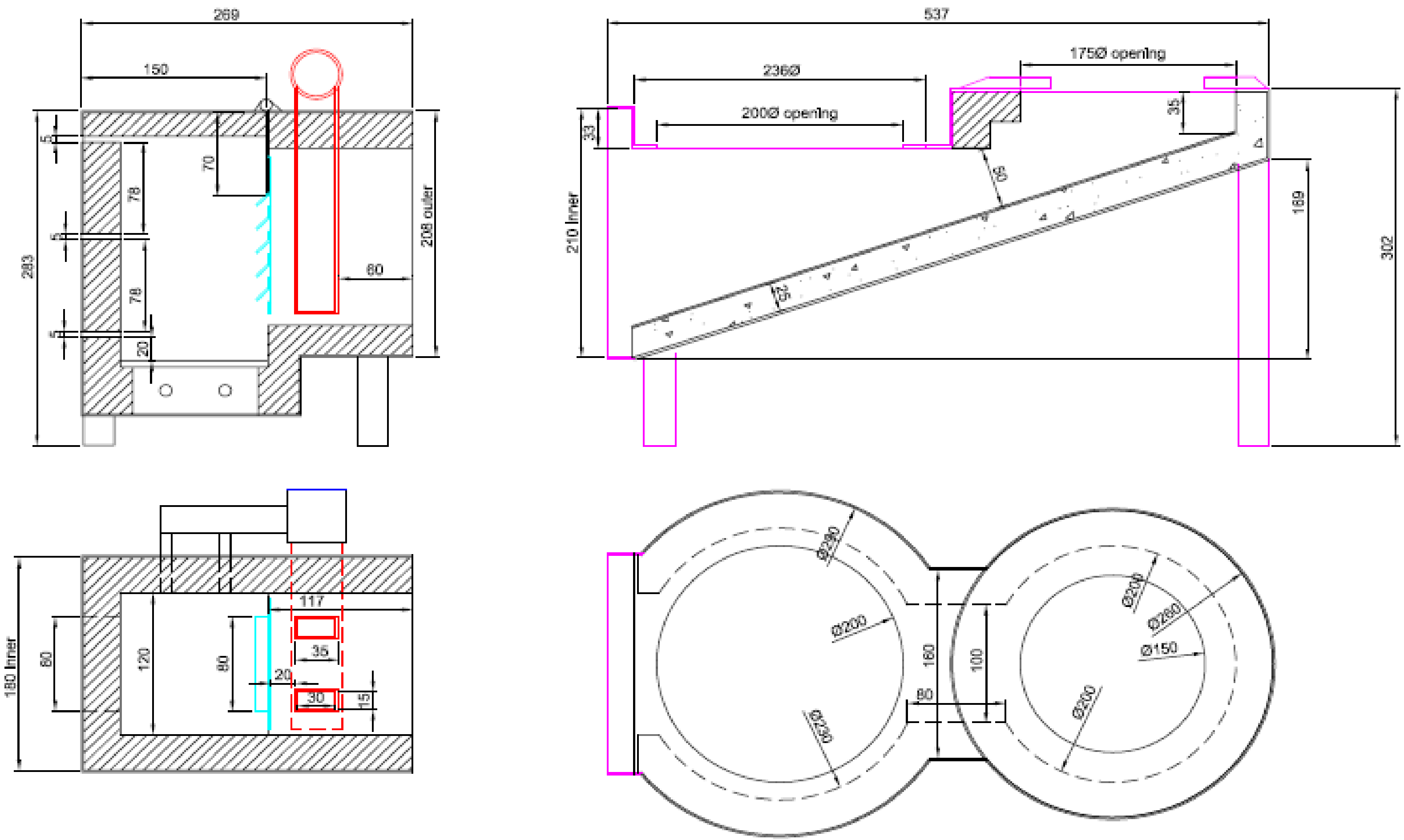
Horizontal combustion offered the possibility of reducing the height of the combustion device something that appeared as a demand from applications.

Aravindakshan: I want a 50 mm lift from this position shown by the arrow for the vessels – both: Rest as in 1 kgph design for combustion system

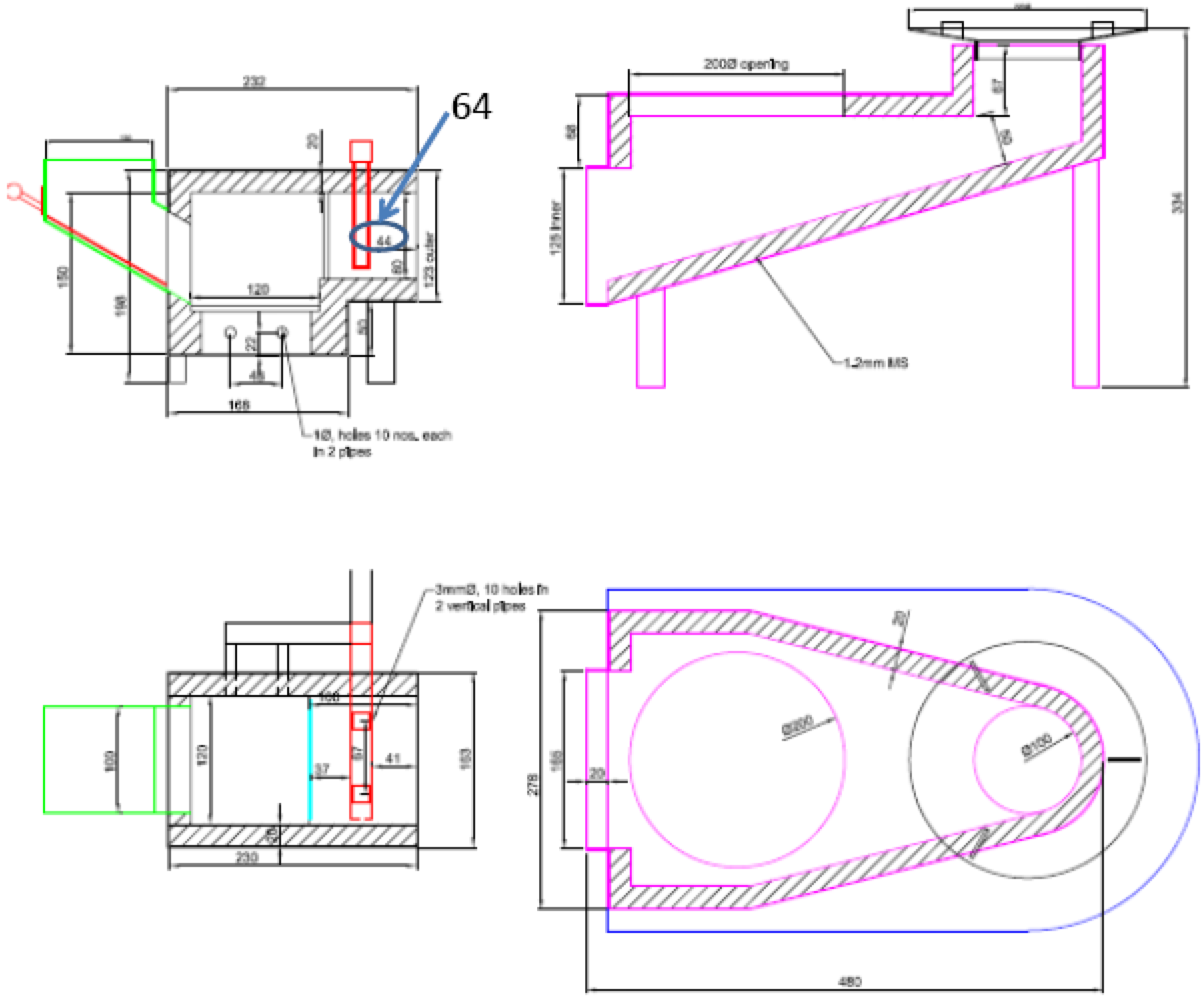



120 mm width,
80 mm high
100 mm longitudinal
section

**Changes contemplated on 17 august 2015**



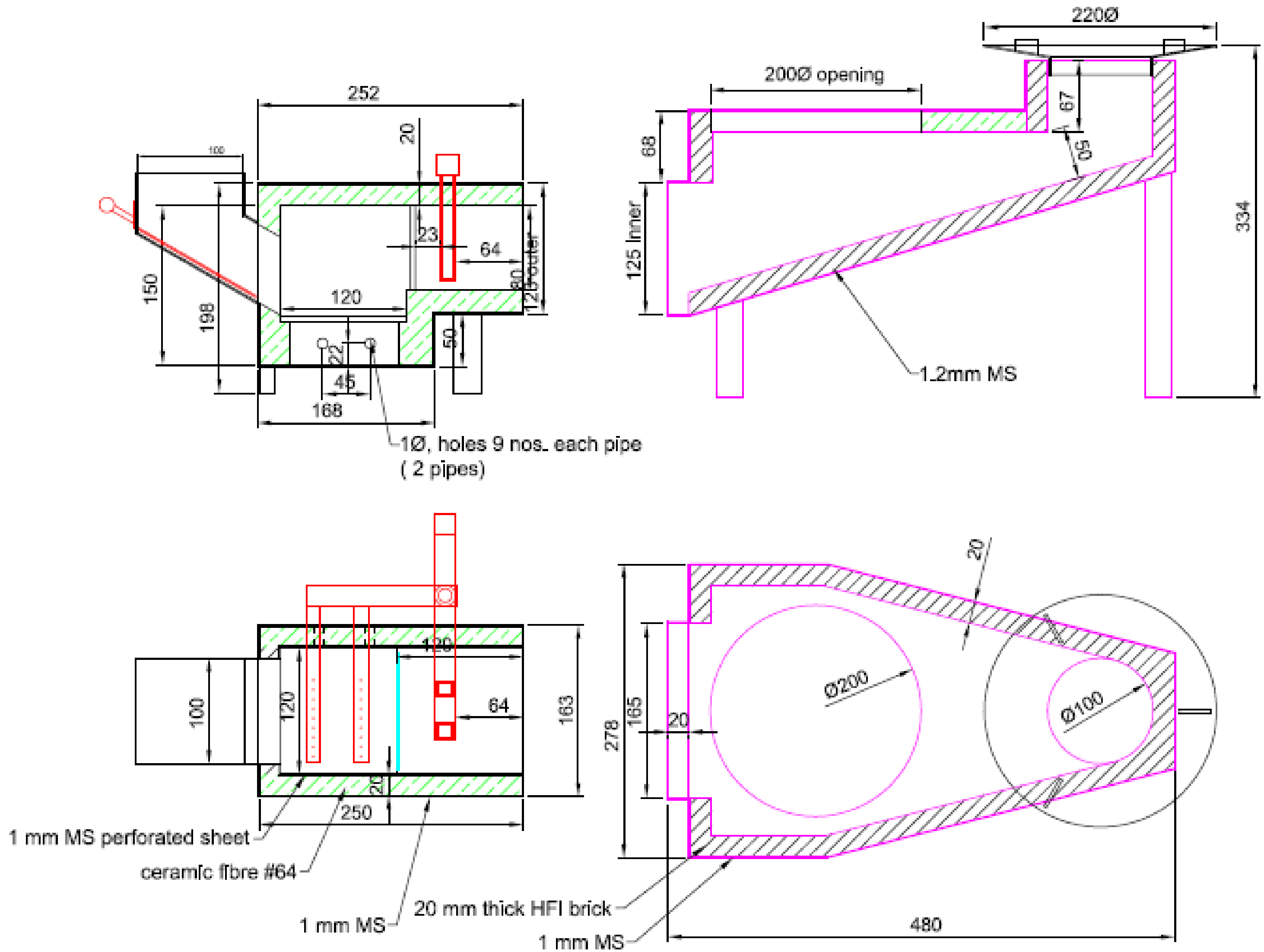

**Two-pan design as on 26 June 2015**




Outer 20 x 20 x 1.2 mm MS frame

Insulation 20 mm thick HFI.

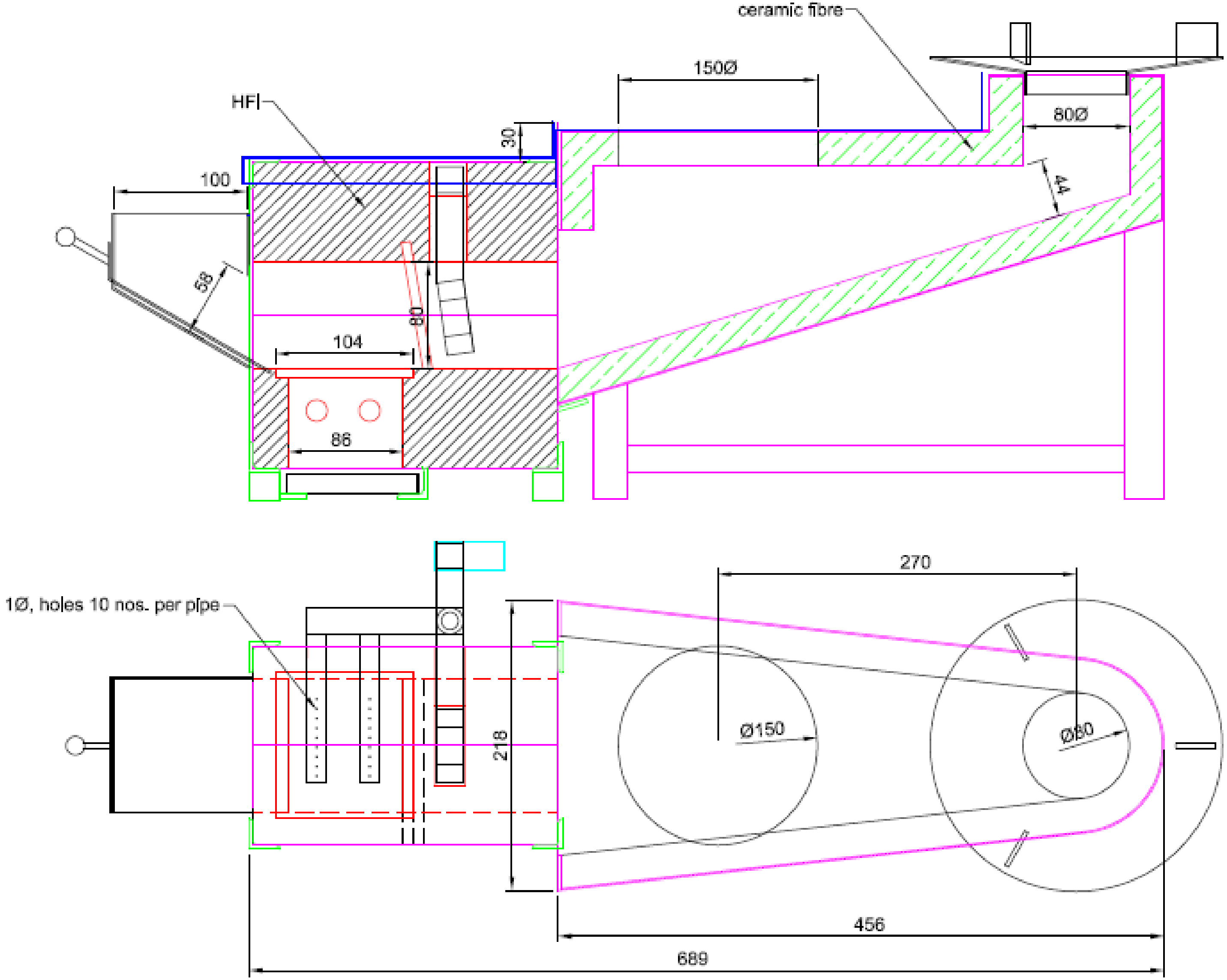
**2 pan device after modifications – 27 August 2015**



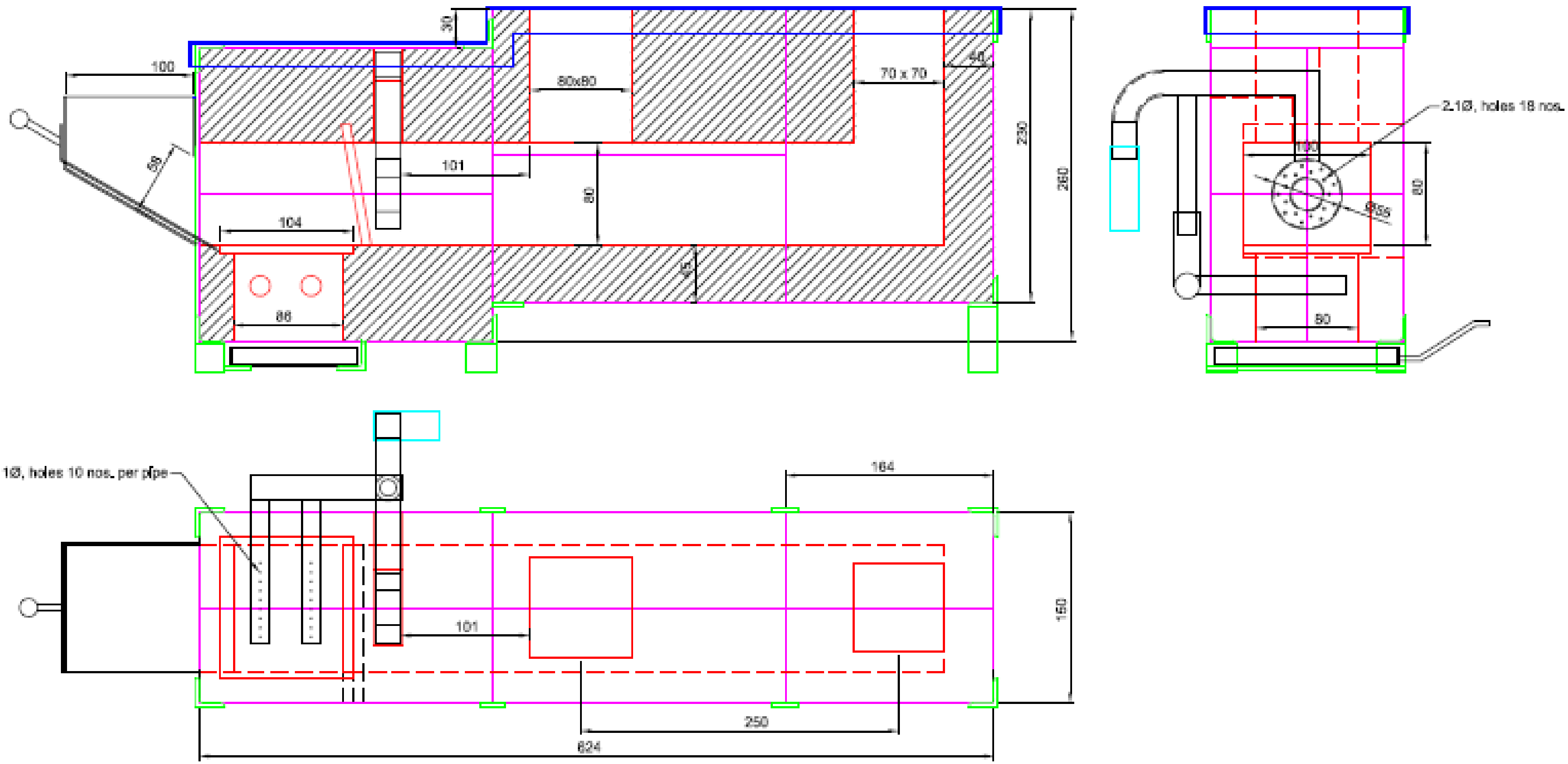

Outer 20 x 20 x 1.2 mm MS frame

1.3 kgph 2 pan parts.

**Two-pan device – 12 September 2015**

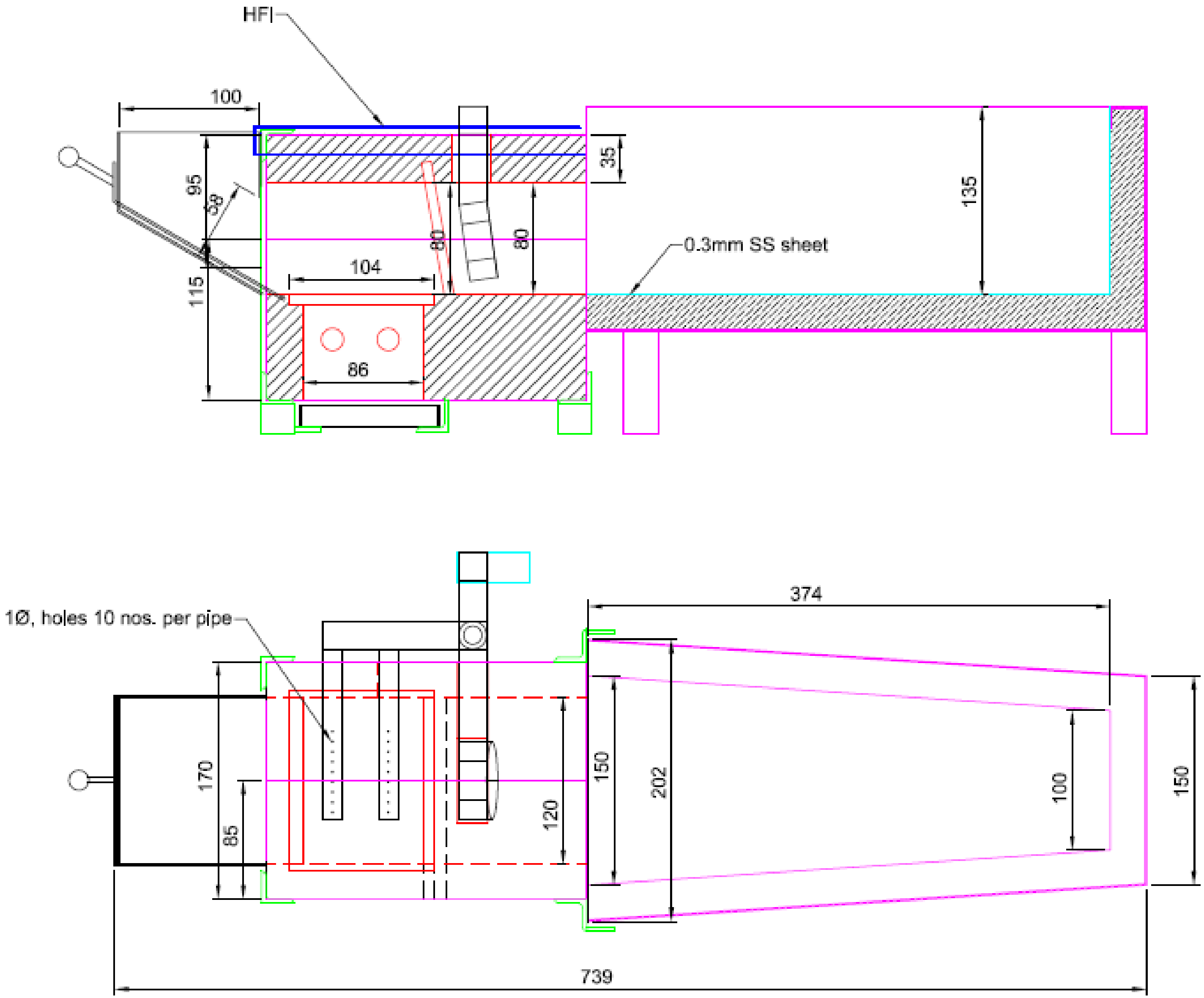



**Design – 9th October 2015;**
**vessel chamber width reduced with axial distance; Circular air injector**



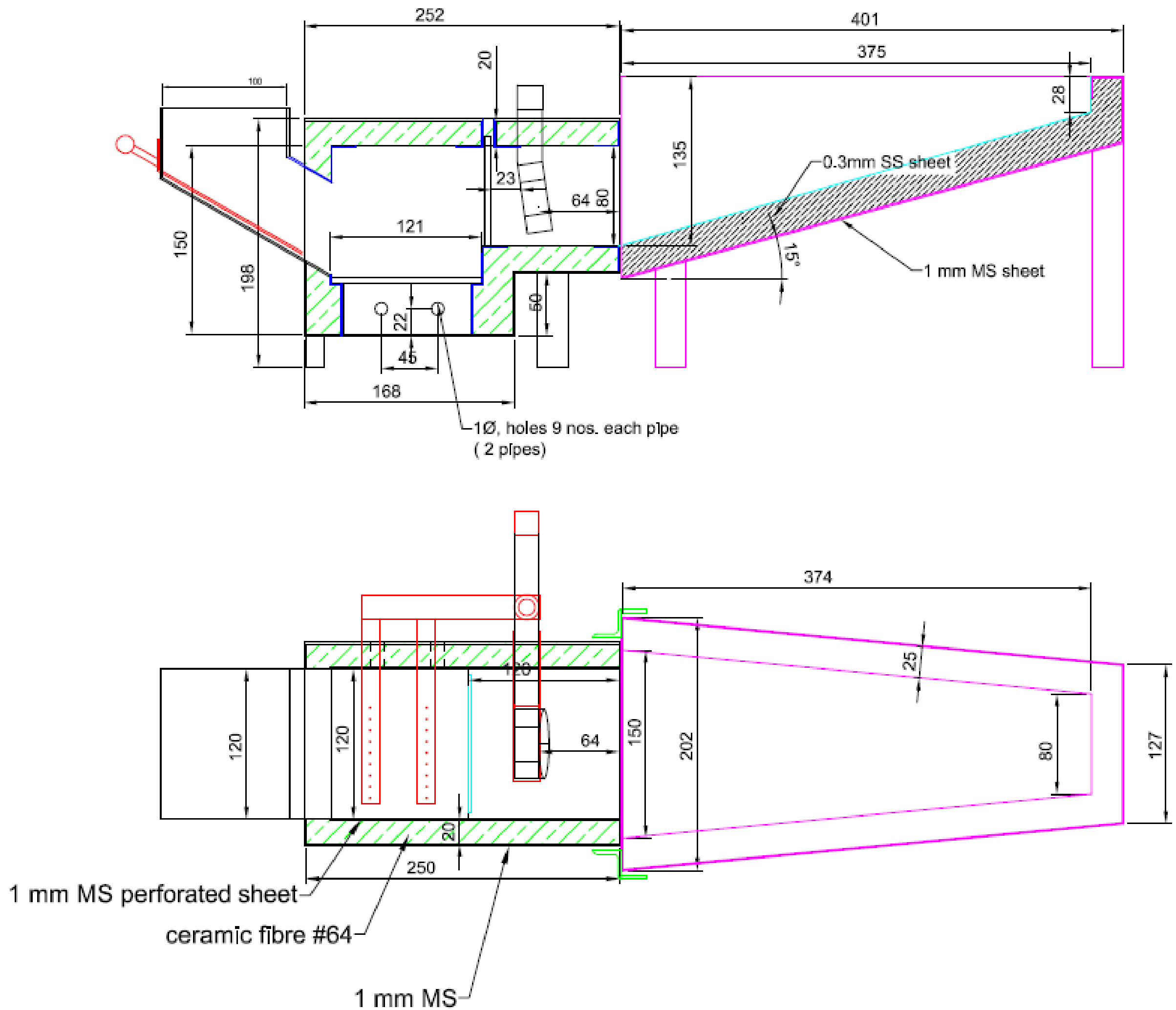

29-9-2015- modified

A design that was attempted to see how bad things can be.
Most energy will be absorbed in the heavy ceramics – weighing 20 kg



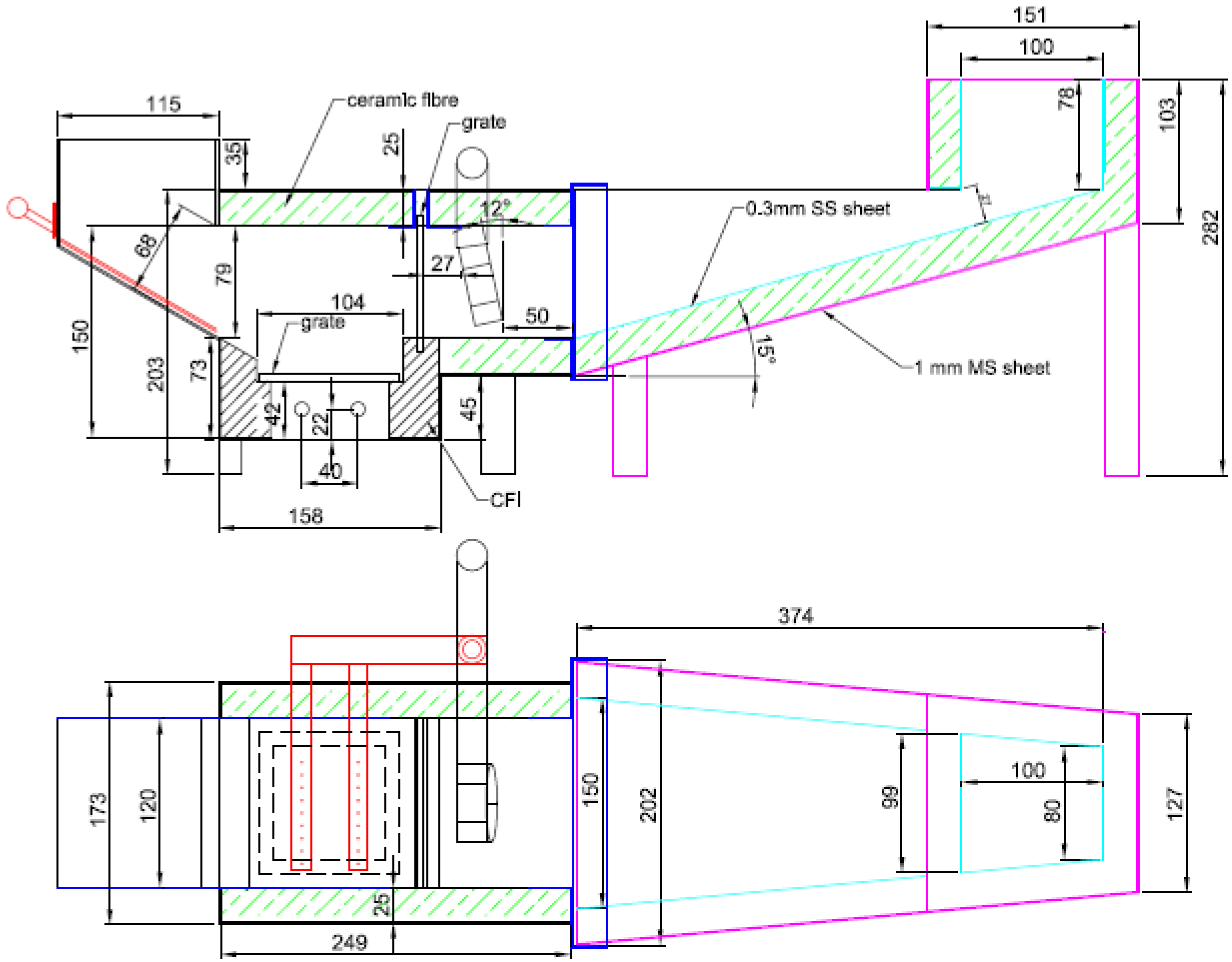

**Design – 13 October 2015**

**vessel chamber width reduced with axial distance; Circular air injector**




# 1 kgph

# 30-10-2015

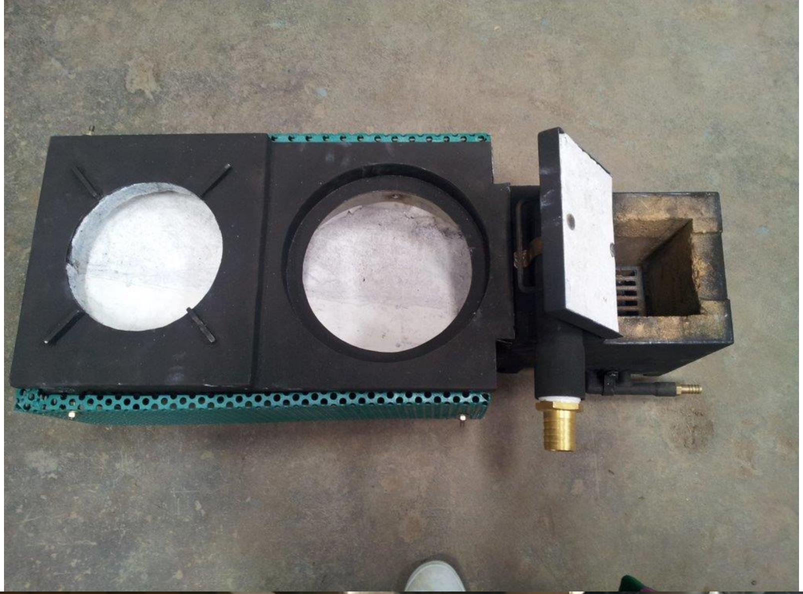



# 1 kgph 2 pan (insulated body ) 28-11-2015

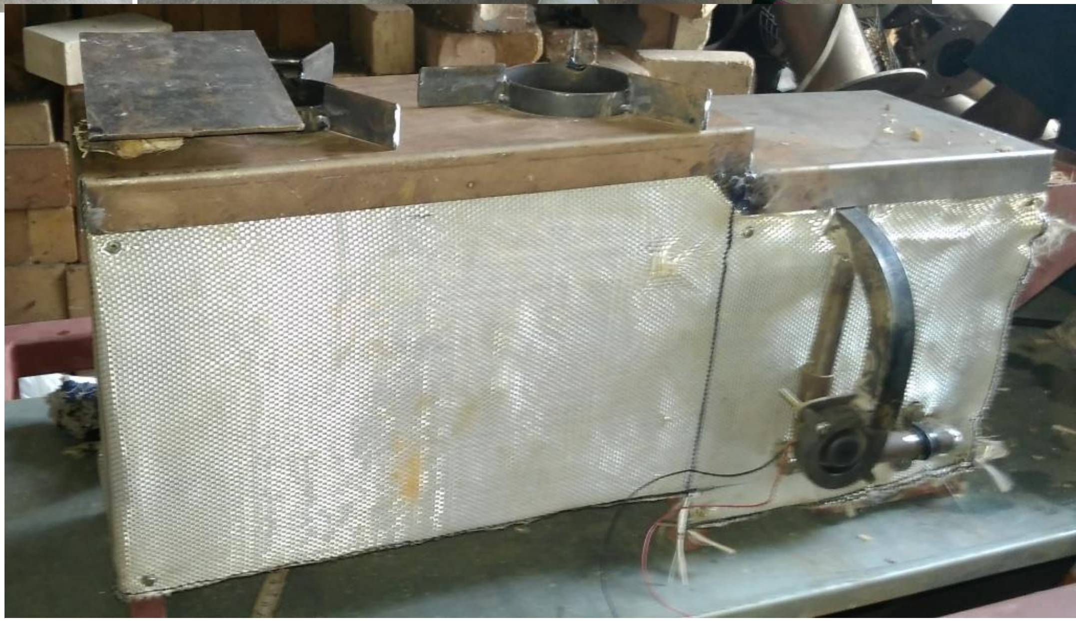
No changes for the combustion system.
Return to earlier ideas of keeping the vessel position close to the jets
Additional ideas of thin Al or SS sheet or fine wire mesh over the combustion space covers for improper use of the system, if at all

Before being clothed from outside

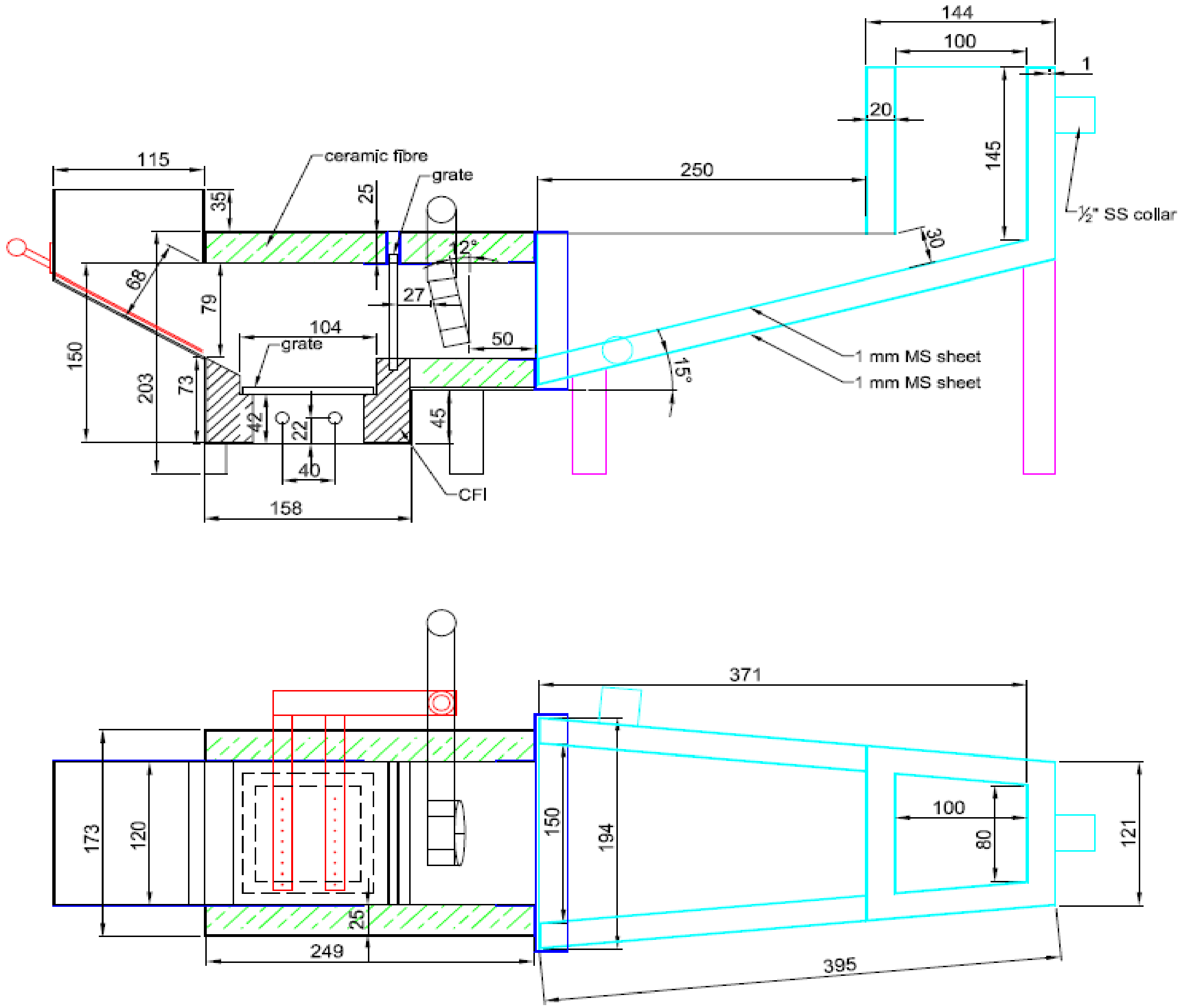
Fire resistant Fiber based outer covering



The first 2-pan design built for
better aesthetics; The choice is
Between steel covering or cheaper
Fire retardant fabric covering



The 2-pan design with vessel supports




1 kgph 2 pan

**The system with outer sections made of double-walled water Jacket to enhance the efficiency and generate hot water for cooking**

# Blowers/air supply system for small systems Details

# On blowers

- Blowers play the crucial role in determining clean combustion.
- Two balancing points – Increased mass flow through the injector holes implies better O/F.
- This can be achieved by increasing the injector hole area with jet velocity controlled by the pressure head of the blower.
- The momentum of the jet is mass flow times the velocity.
- In blowers, it is possible to maintain the same mass flow rate but increasing the momentum flux by decreasing the jet cross sectional area but increasing the pressure head so that the jet velocity is increased to maintain the same air flow rate $A_{jet} = \acute{m}/\rho\ V_{jet}$, where $\acute{m}$ is the mass flow rate (*kg/s*), $\rho$ is the air density (~ 1 $kg/m^3$), $V_{\mathbf{jet}}$ is the jet velocity in *m/s*. This gives $A_{jet}$ in $m^2$.
- The momentum flux and the mass flow rate are deeply coupled in small blowers and it may not be possible to change by keeping the other constant.
- A further important variable is the exposed cross section of the fuel bed.
- For large power levels, the fuel flux through the port can be set at 100 to 300 kg (fuel) /$m^2$h. To exemplify this, if we choose 200 fuel flux of 200 kg (fuel) /$m^2$h for a 20 kg/h system, one gets 0.1 $m^2$ as the fuel cross sectional area. This can be chosen as 300 mm x 300 mm or 500 mm wide x 200 mm high (for 0.1 $m^2$ area) depending on the application.
- Typical values for small power systems are set out…..

# Single pan and two pan systems

1. Single pan, 100 mm (stove axis) x 100 mm (width) x 80 mm (height) with air nozzles of 2.5 mm dia x 18 holes or 3 mm dia x 12 holes will give about 1.1 kg/h (translating to fuel flux of 135 $kg/m^2h$). This works well with SUNON GB1205PHVX-8AY. This is the recommended blower. It runs at full load (when the 15 mm x 15 mm air delivery is open) at 6750 – 6800 rpm and at no load (when air exit is closed) at 10,000 rpm. The latter data is not included in their data sheets. At intermediate loads it runs at different speeds.
2. Single pan, 100 mm (stove axis) x 100 mm (width) x 100 mm (height) with air nozzles of 2.5 mm dia x 18 holes or 3 mm dia x 12 holes will give about 1.3 kg/h (translating to fuel flux of 110 $kg/m^2h$). This works with SUNON GB1205PHVX-8AY. Occasional fuel richness may result in this configuration.
3. Two pan, 120 mm (stove axis) x 120 mm (width) x 80 mm (height) with air nozzles of 2.5 mm dia x 18 holes or 3 mm dia x 12 holes will give about 1.4 kg/h (translating to fuel flux of 140 $kg/m^2h$). This works well with SUNON GB1205PHVX-8AY.
4. Two pan, 120 mm (stove axis) x 120 mm (width) x 100 mm (height) with air nozzles of 2.5 mm dia x 18 holes or 3 mm dia x 12 holes will give about 1.5 kg/h (translating to fuel flux of 150 $kg/m^2h$). This works well with SUNON GB1205PHVX-8AY. In a 2-pan configuration, there will be no sooting because of good combustion due to some air being drawn at the front end of the vessel seating chamber (or "boat"). Vessel seating at the front end should have 15 mm spacers and the seating at the aft end should have 5 mm spacers.
5. The air holes must be drilled sharply without shamfer.

Blowers


AMBEYOND

Sunon-5 V



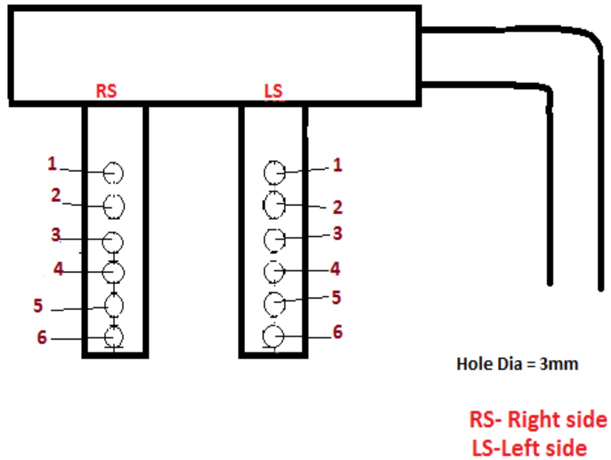
New Sunon
Runs at 5500
Rpm?

Old Sunon
12 V

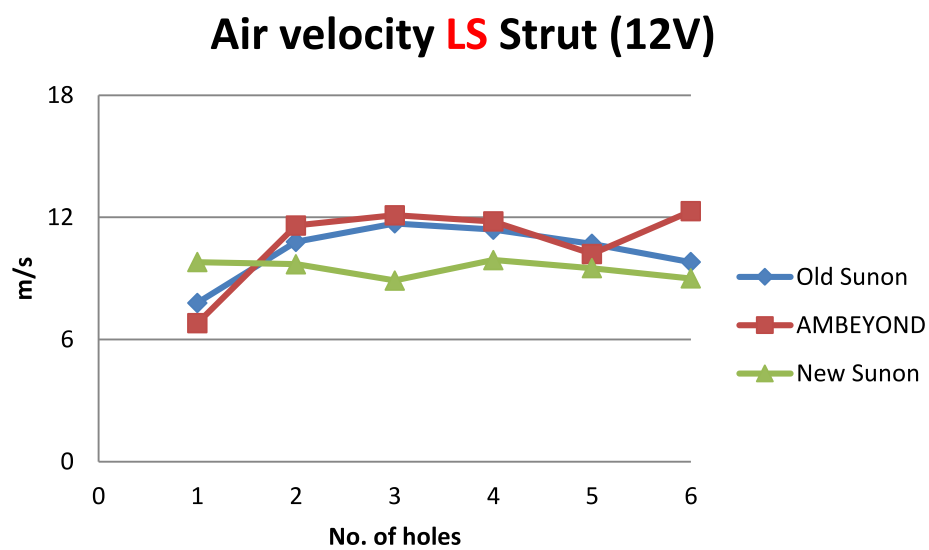

| Blower | Model | V, DC | Blower rpm |
|---|---|---|---|
| Old Sunon | GB1205PHVX-8AY | 12 | 6820 |
| New Sunon | GB1205PHVX-8AY | 12 | 5500 |
| Ambeyond | AV-F5015SMS | 12 | 6300 |
| Sunon | MF50150VX | 5 | 6000 |

# Performance details

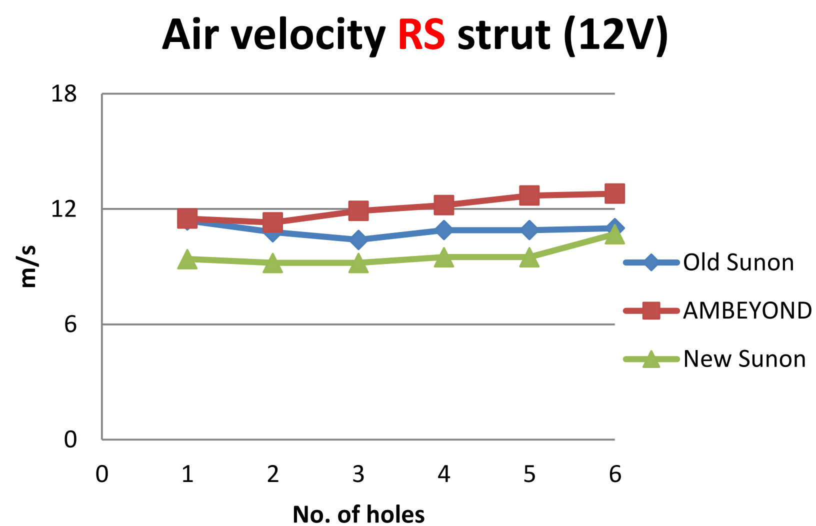
| Type | Comb_Chamber mm (WxD) | Ht of Comb_Chamber mm (H) | Air system shape | No of struts | No of holes in struts (Air system) | Air system | | Type of blower used | Air velocity m/s | Power system (kg/hr) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | OD holes PCD45 | ID holes PCD35 | Sunon | | |
| 1-Pan | 100x100 | 80 | Rectangular | 2 | Dia 3X12 | | | 12V | 10.5 to 11.5 | 1.07 |
| 2-Pan | 120x120 | 85 | Circular | 2 | Dia 3X12 | 9 | 9 | 12V | 10.5 to 11.5 | 1.5 |
| 2-Pan | 120x120 | 100 | Rectangular / Circular | 2/1 | Dia 3x12 / Dia 2.5x18 | 9 | 9 | 12V | 10.5 to 11.5 | 1.5 |



RS
LS
1
2
3
4
5
6
Hole Dia = 3mm
RS- Right side
LS-Left side

Air velocity LS Strut (12V)
18
12
6
0
m/s
0
1
2
3
4
5
6
No. of holes
Old Sunon
AMBEYOND
New Sunon

Air velocity RS strut (12V)
18
12
6
0
m/s
0
1
2
3
4
5
6
No. of holes
Old Sunon
AMBEYOND
New Sunon

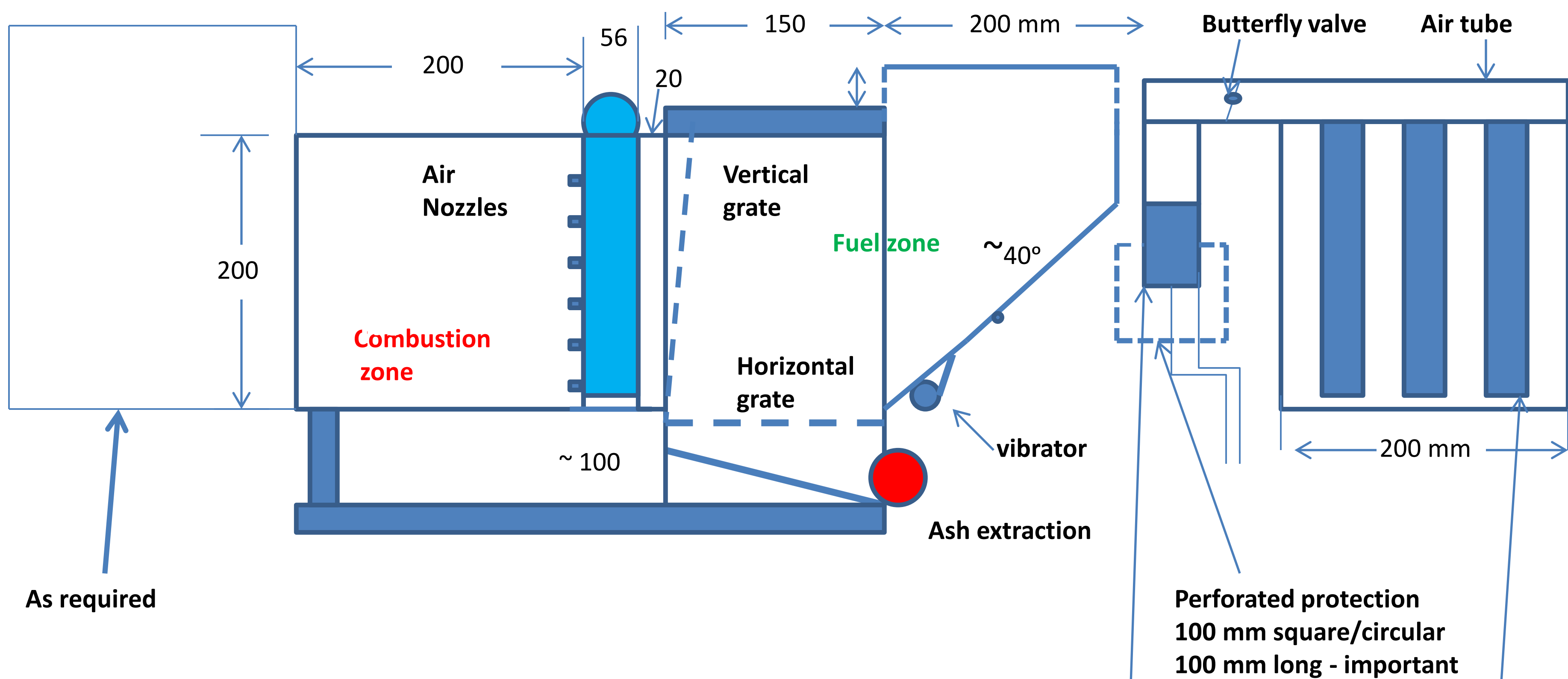
| Old- GB1205PHVX-8AY | | |
|---|---|---|
| Sl .no | RS (m/s) | LS (m/s) |
| 1 | 11.4 | 7.8 |
| 2 | 10.8 | 10.8 |
| 3 | 10.4 | 11.7 |
| 4 | 10.9 | 11.4 |
| 5 | 10.9 | 10.7 |
| 6 | 11 | 9.8 |
| | RPM | |
| Open | 6800 | Good |

| AV-F5015SMS | | |
|---|---|---|
| Sl .no | RS (m/s) | LS (m/s) |
| 1 | 11.5 | 6.8 |
| 2 | 11.3 | 11.6 |
| 3 | 11.9 | 12.1 |
| 4 | 12.2 | 11.8 |
| 5 | 12.7 | 10.2 |
| 6 | 12.8 | 12.3 |
| | RPM | |
| Open | 6300 | Not good |

| New- GB1205PHV1-8AY | | |
|---|---|---|
| Sl .no | RS (m/s) | LS (m/s) |
| 1 | 9.4 | 9.8 |
| 2 | 9.2 | 9.7 |
| 3 | 9.2 | 8.9 |
| 4 | 9.5 | 9.9 |
| 5 | 9.5 | 9.5 |
| 6 | 10.7 | 9.0 |
| | RPM | |
| Open | 5500 | Not good |

| Blower | Model | V, DC | Blower rpm |
|---|---|---|---|
| Old Sunon | GB1205PHVX-8AY | 12 | 6820 |
| New Sunon | GB1205PHVX-8AY | 12 | 5500 |
| Ambeyond | AV-F5015SMS | 12 | 6300 |
| Sunon | MF50150VX | 5 | 6000 |

# Larger power systems



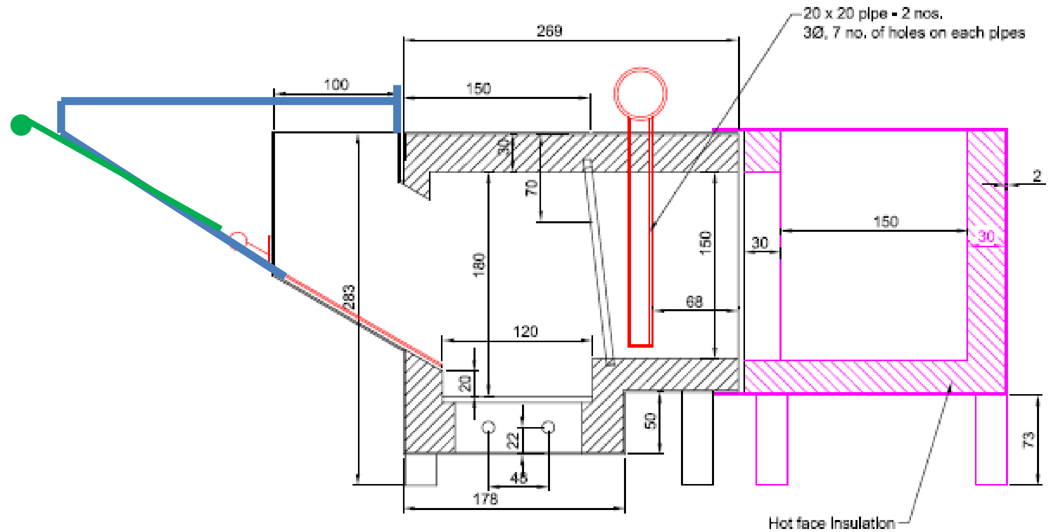

Blower running at
17000 rpm to be fixed
suitably to the casing.

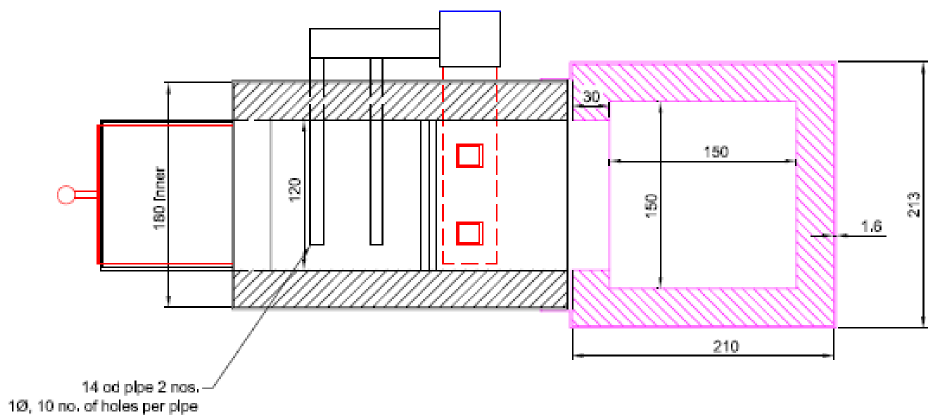
All dimensions - mm

The same configuration is valid for
2.5 to 5 kg/h. The number of air nozzles
increase from 18 (2.5 mm dia) at 2.5 kg/h
to 36 (2.5 mm dia, 12 in each strut) at 5 kg/h

Air supply struts 3 in No,
15 mm x 56 mm size
spaced 50 mm center-to-
center distance.
Air holes 2.5 mm dia
6 holes equally spaced
from bottom up on each strut

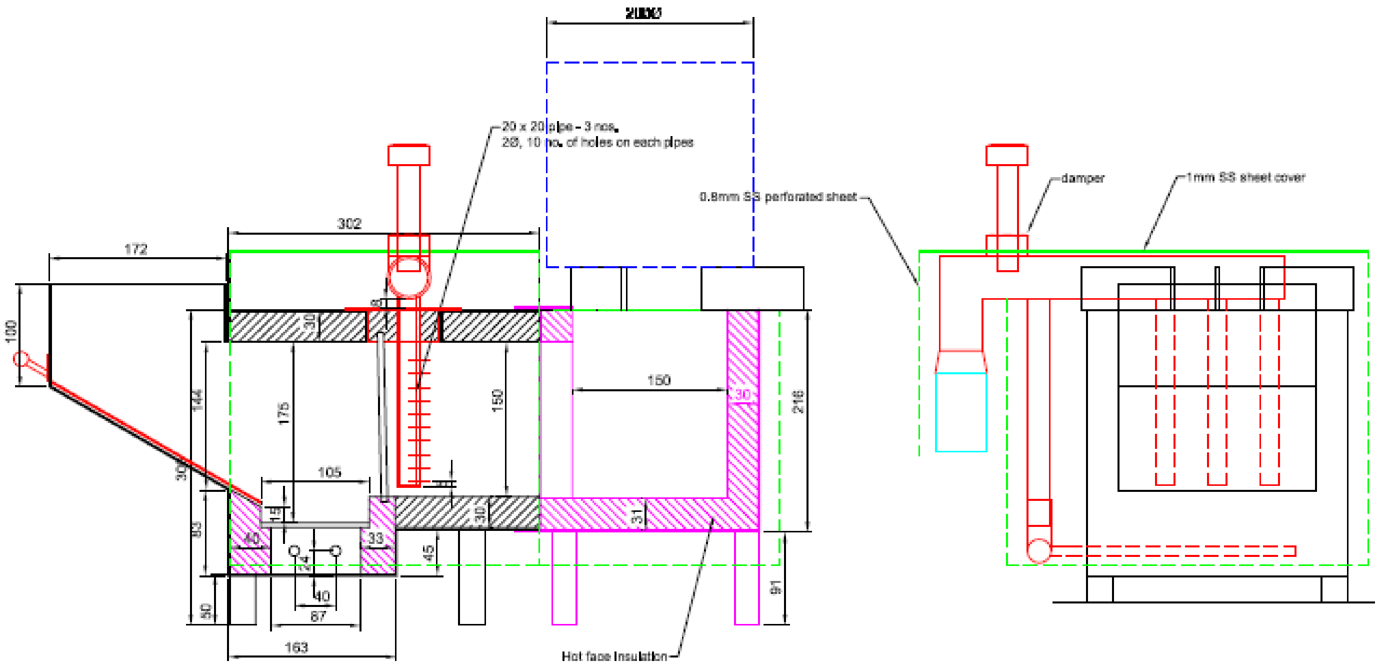
## 2 – 5 kg/h design using a SUNON-class blower

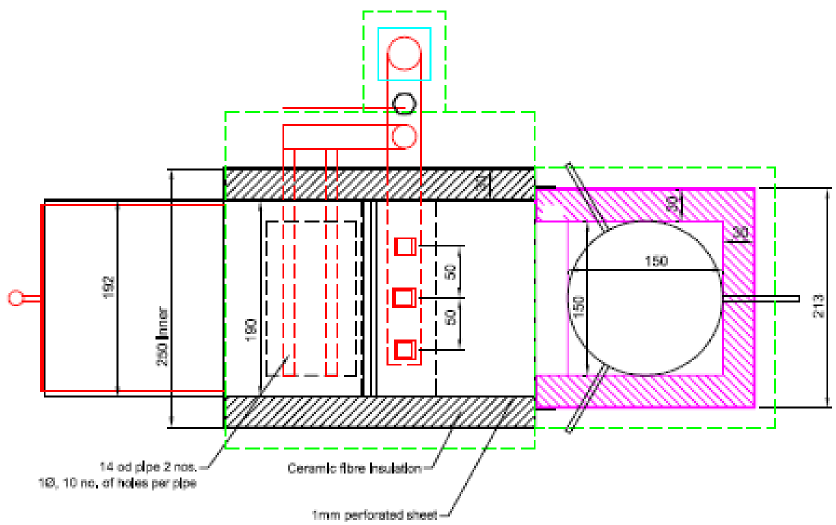



3.5kgph
26-10-2015

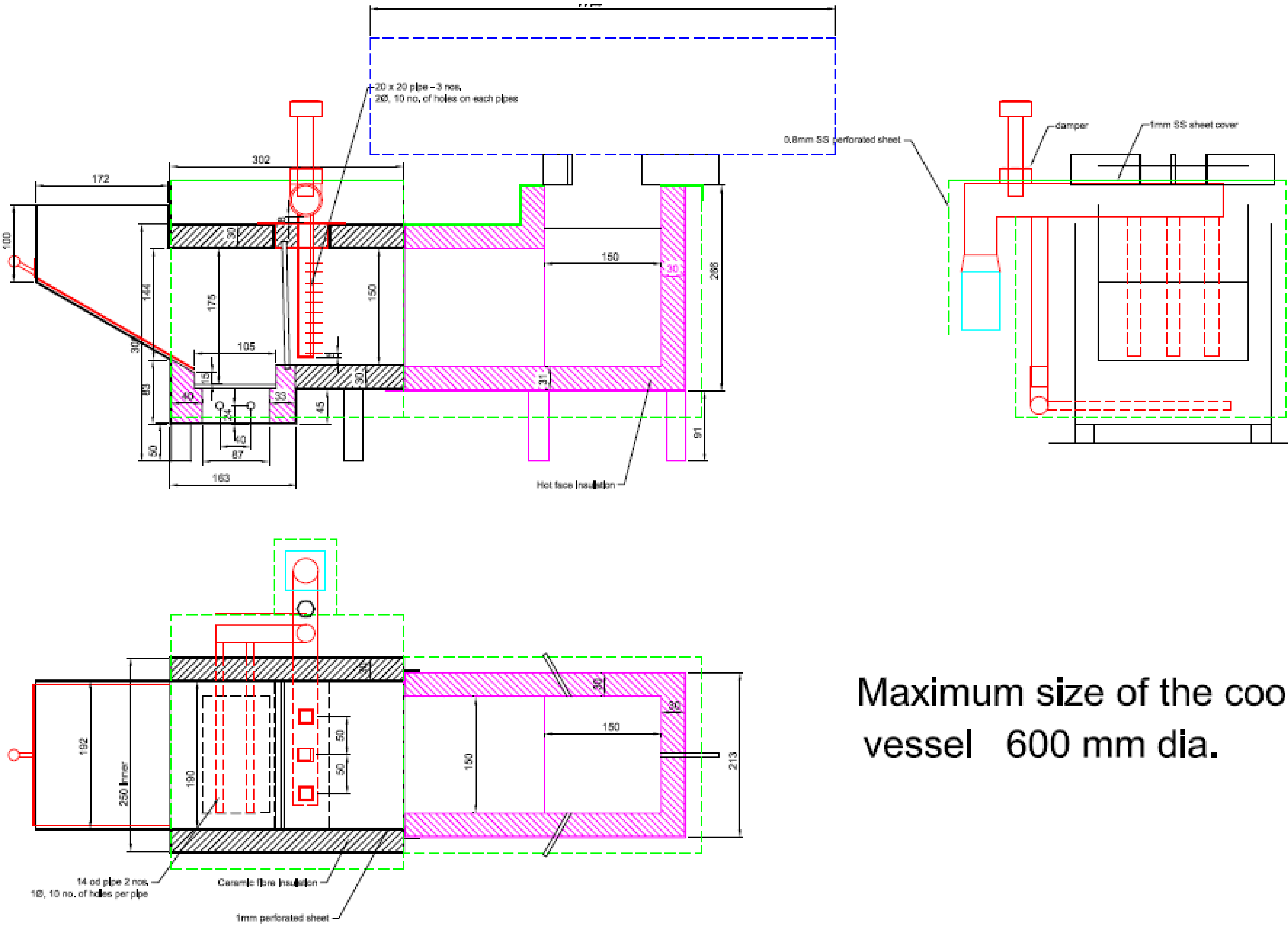
3 kg/h system on test at the laboratory
and use at Mother Teresa's home




Maximum size of the cooking vessel 200 mm dia.

3.5kgph basic design




Maximum size of the cooking vessel 600 mm dia.

3.5kgph for bigger vessel

150 kg/h system
fabricated and shipped to site
for test and operations by
early January 2016

# Design features

The air-to-fuel ratio required is about 3. This is based on the experience at power levels up to 30 kg/h. Additional air for combustion is drawn from the horizontal packed bed.

For 150 kg/h, the air to be drawn is 450 $m^3/h$ (125 lit/s). At jet velocity of 50 m/s, the injector are = 25 $cm^2$
If we take 3 mm dia nozzles (area = 7 $mm^2$) and a jet velocity of 50 m/s, flow rate per nozzle is 0.35 lit/s.
Thus we need 125/0.35 ~ 360 nozzles to pass the flow. This has to be provided in a number of vertical struts of 480 mm long (500 mm is the height). We take a spacing of ~95 mm between the struts so that we can provide 20 struts.

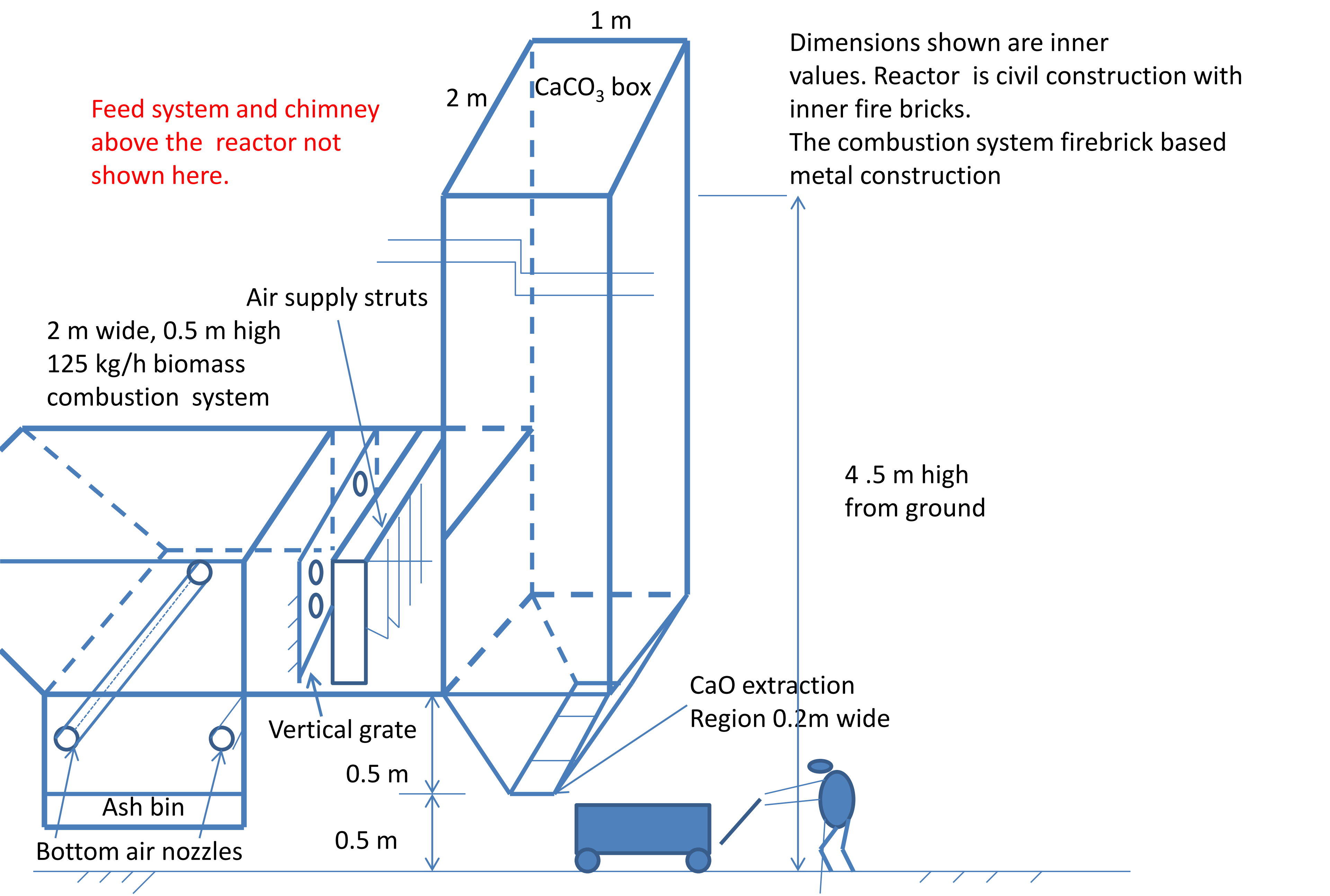
Thus each strut should have 18 holes. The spacing of the holes is 25 mm .

The primary tube carrying air can be allowed to have a maximum velocity of between 5 to 10 m/s. This means an area of 250 $cm^2$ to 125 $cm^2$. We choose a 150 mm dia tube to get an area of 176 $cm^2$ leading to a velocity of 7.1 m/s. This is accepted.

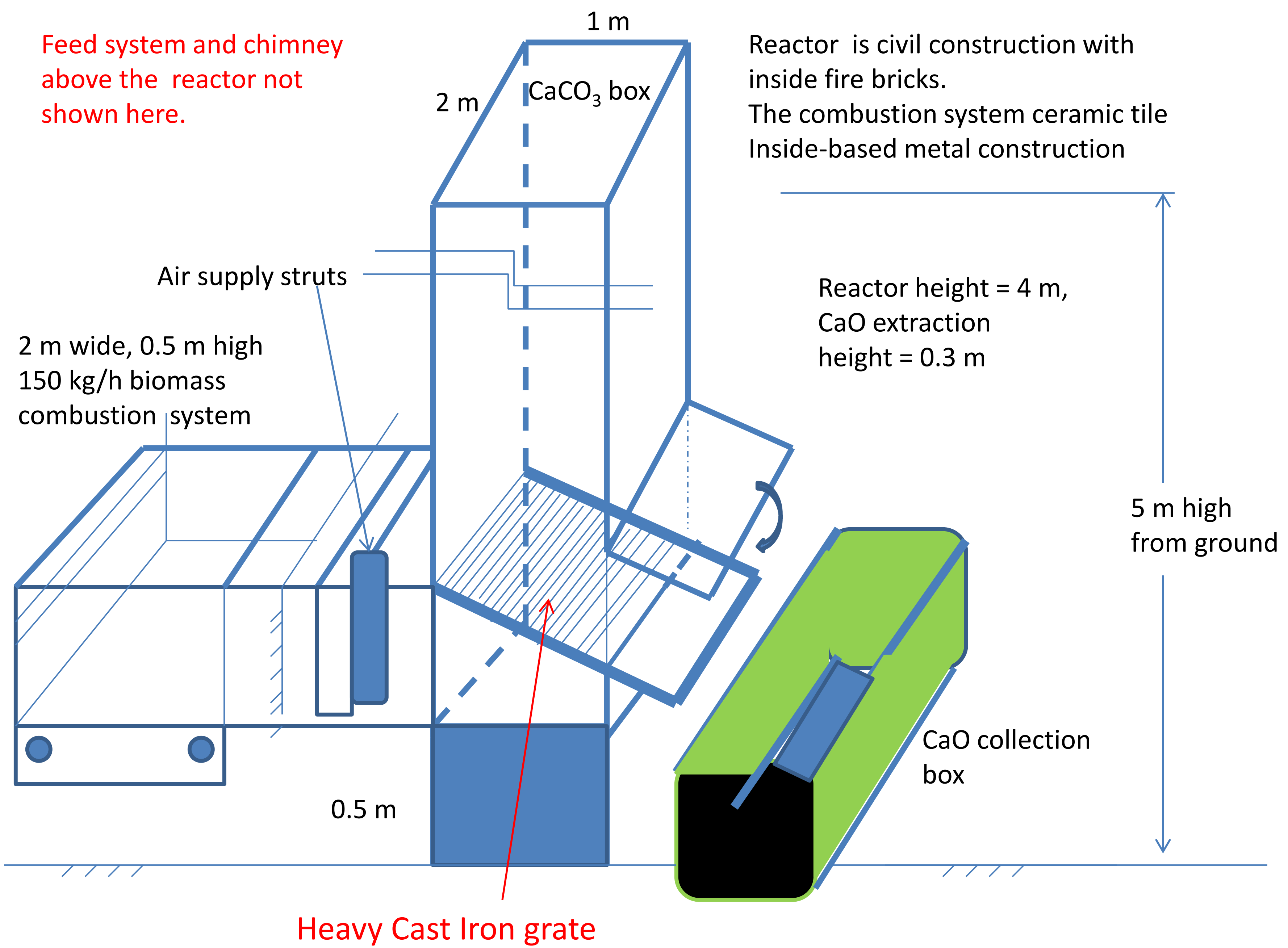
Each strut passes about 6.25 lit/s of air. At velocities of 7.1 m/s, the cross section of the strut would be 8.8 cm2. This needs rectangular section of about 20 mm wide x 80 mm deep. One could choose other cross sections to benefit from available rectangular tubes.

The bottom air should be 300 $m^3/h$. At 30 m/s velocity, this leads to injector area of 30 $cm^2$. On each of the two bottom tubes, one needs to provide 1mm wide slot over 0.75 m length in an interrupted way roughly as Follows:

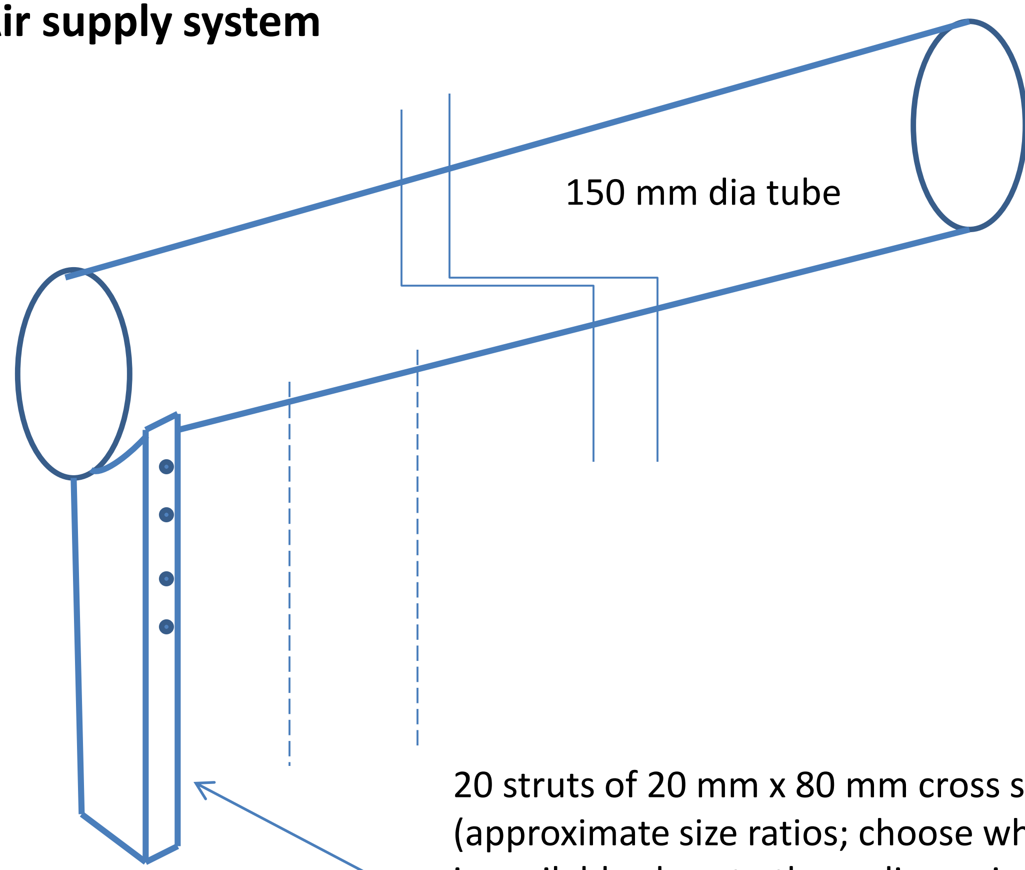
2 mm wide interrupted slots



1 m
2 m
$CaCO_3$ box
Dimensions shown are inner values. Reactor is civil construction with inner fire bricks.
The combustion system firebrick based metal construction
Feed system and chimney above the reactor not shown here.
Air supply struts
2 m wide, 0.5 m high 125 kg/h biomass combustion system
4 .5 m high from ground
CaO extraction Region 0.2m wide
Vertical grate
0.5 m
0.5 m
Ash bin
Bottom air nozzles

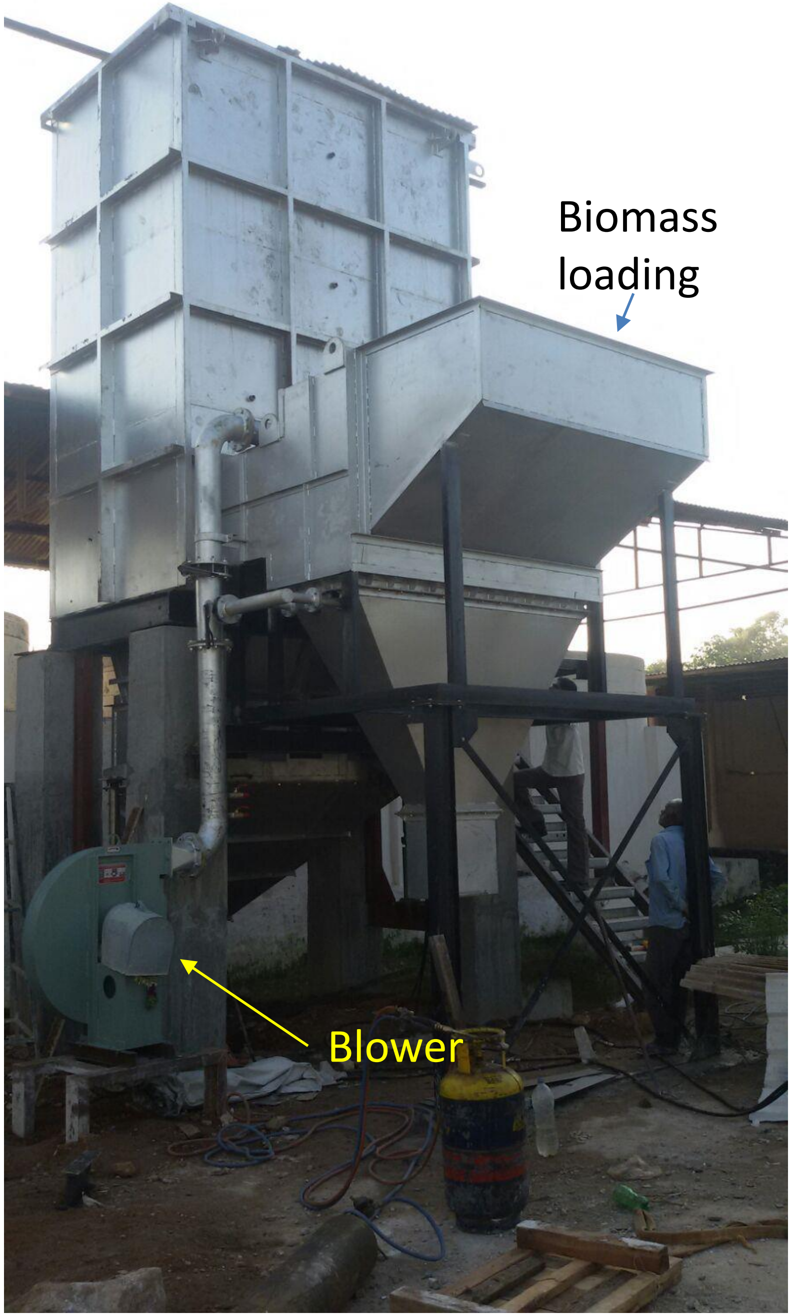

Feed system and chimney above the reactor not shown here.
1 m
2 m
$CaCO_3$ box
Reactor is civil construction with inside fire bricks.
The combustion system ceramic tile
Inside-based metal construction
Air supply struts
2 m wide, 0.5 m high
150 kg/h biomass
combustion system
Reactor height = 4 m,
CaO extraction
height = 0.3 m
5 m high
from ground
CaO collection
box
0.5 m
Heavy Cast Iron grate

## Air supply system




20 struts of 20 mm x 80 mm cross section
(approximate size ratios; choose what
is available close to these dimensions) spaced
95 mm apart within a width of 2000 mm

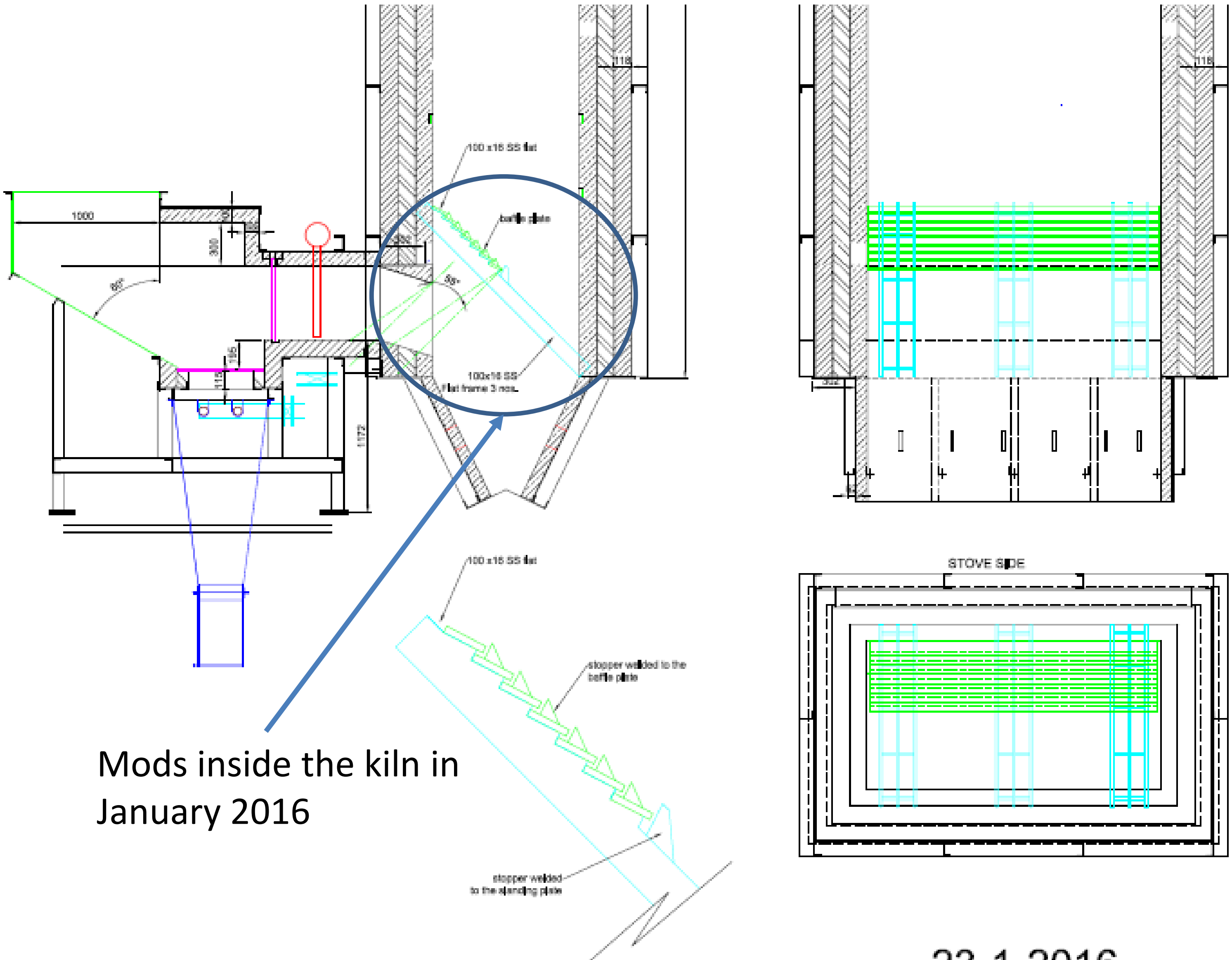
The 150 kg/h before being set out with firebricks
Inside and set for shipment




**Two views of 150 kg/h Biomass combustion based Lime kiln in Tirunelveli**

**Constructed on schedule by Mr. Aravindakshan of Zigma Engineering Co**

**Development partner of FEAST**




Mods inside the kiln in January 2016

23-1-2016

## Three modifications to the fuel feed zone to facilitate automatic movement and reduced periodicity of loading

1. A perforated sheet based container 1 m x 2m x 0.5 m

2. Additional plate over the bottom plate as in smaller combustion systems

3. Three vertical rods along the 2 m length connected to the plate and moved up and down at some frequency using a geared motor