Supplement

Finding a Clean Woodstove – A 300-Year Quest
Islam and Smith

Justell's Machine

PHILOSOPHICAL
TRANSACTIONS:

An account of an engine that consumes smoak, shown lately at St. Germans fair in Paris

Mr. Justell R. S. S.

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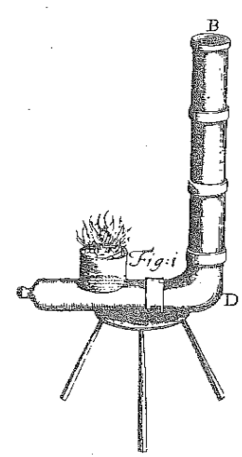

FIGURE 3.11 Justel's smokeless stove which could consume sardine oil or cat's urine without offence

lately at St. Germans Fair *in* Paris *Communicated by* Mr. Just. ll R.S.S.

TO *burn all sorts of Wood in the middle of a Room without making any* Smoak, *is a thing so extraordinary, that all those that have heard speak of it, as well Philosophers as others, have asserted it impossible: but Mr.* Dalesme *Enginier, prosecuting his discoveries, has found out a Machine, which tho very little and portable, consumes all the* Smoak *of all sorts of Wood whatsoever, and that so, that the most curious eye cannot discover it in the Room, nor the nicest Nose smell it, altho' the Fire be perfectly open. This has given such satisfaction to all that have seen it, and to the King himself, that he has caused the Experiment to be made several times* before Him.

This Engine is made after the manner represented in Fig. 1. *and is composed of several hoops of hammer'd Iron of about 4 or 5 Inches diameter, which shut one into the other: It stands upright in the middle of the Room, upon a sort of Trevet made on purpose. A is the place where the Fire is made, where if you put little peices of Wood, it will not make the least smoak, neither at A nor* B, *over which you cannot hold your hand within half a foot, there comes out so great a heat: If you take one of these peices of Wood, out of the Fire at A, it smoaks presently, but ceases immediately so soon as it is cast in the Fire again. The most fœtid things, as a Coal steept in Cats-piss, which stinks abominably when taken out of the Fire, notwithstanding in this Engine makes not the least ill scent. The same did Red-Herrings broiled thereon; on the other side all perfumes are lost in it, and Encense makes no smell at all, when burnt therein. We have since learnt that this is not shown, but when the Fire at A is well kindled, and the Tunnel* B D *very hot, so that the Air that feeds the Fire cannot come that way, but must all press in upon the open Fire; whereby the* Smoak *and* Flame *is all forced inwards, and must pass through the heap of burning Coals in the Furnace A, in which passage the parts thereof are so dispersed and refined, that they become inoffencive both to the Eye and Nose.*

A

Supplement 1: Experimental Apparatus - Burner System

Downdraft combustion was studied in (a) a 75 mm inside diameter quartz tube combustor, and (b) a steel tube combustor of similar dimensions, using a combination of induced and natural draft airflow. The combustor was designed with the aid of Reed's (1983) dimensions for a stratified downdraft gasifier to achieve a nominal 1 kg/hr firing rate which is the approximate average firing rate of fuel use on a woodfired cooking stove. A schematic diagram of the burner, air supply and exhaust system is shown in Figure S-1.

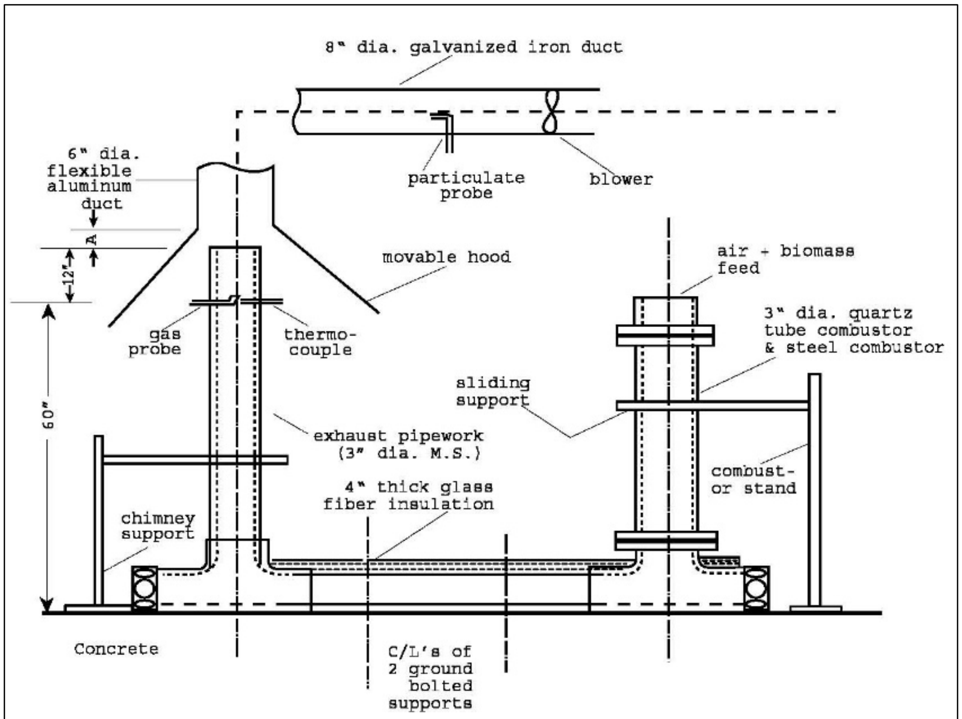

Figure S-1: Burner, air supply and exhaust system

The system can broadly be divided into three portions: quartz tube combustor, stove pipework and flue gas induction arrangement. Air and biomass are fed into the reaction zone of the quartz tube (or steel tube) from the top to the tube. After the reaction, the flue gases pass into the stove pipework. The latter consists of' a 75 cm horizontal length of 75 mm dia. (nominal), malleable iron pipe, which was insulated with a 100 mm thick glass fiber insulation to prevent condensation of particulates. The horizontal pipe is followed by a 1.5 m length of vertical pipe of the same type, which acts as chimney to the combustor. The stove pipework is a tentative means of implementing downdraft combustion in a practical stove. One foot below the exit of' the stove pipework is attached a gas sampling probe leading to the gas sampling train. Adjacent to the gas sample probe, a type E thermocouple is attached for measurement of flue gas temperature at this point. The centerline of the chimney is co-axial with the 150 mm diameter opening of a movable hood. A small winch is provided in order to change the position of the exhaust hood. This enables control of the induced airflow through the combustor and causes cool ambient air to be pulled in along with the hot gases. The diluting air condenses the vaporized tar in the flue gas into aerosol droplets (Butcher and Ellenbecker, 1982; Macumber and Jaasma, 1981). The diluted flue gas is exhausted through a 200 mm diameter galvanized iron duct circuit powered by a 1/3 hp blower, and controlled by a damper. The transparency of the quartz tube, fabricated by GM Associates Inc. California, allows important visual observations to be made during fuel loading, fuel ignition, and fuel feeding and also permits various bed dimensions to be measured during operation. The tube is 75 mm inside diameter, 75 cm long and has flat 0-ring joints at both ends. On top of the tube sits a steel cylindrical inlet section which houses a hot wire anemometer probe. An ash grate fabricated out of expanded metal mesh mounted in a steel ring is located 75 mm above the bottom of the quartz tube and supports the bed of reacting material. It is held in place by four steel stranded wire cords attached to the grate support ring. The reactor tube is clamped to a steel transition piece by a Thomas pinch clamp. Sealing of the quartz/steel joint is effected by a 5 mm thick, high temperature, viton O-ring sandwiched between two ceramic paper gaskets. The transition piece joins the reactor tube to the stovepipe at a pipe tee. One leg of the tee serves as the cleaning port while the other leads toward the flue exhaust.

Supplement 2: Instrumentation Setup

Instrumentation was provided in order to measure various quantities of interest in this study. Figure S-2 shows a schematic diagram of the instrumentation in relation to the burner system. Airflow into the combustor was measured at the combustor inlet with a DISA 55M-System hot wire anemometer. This anemometer could be operated in either the constant current (CCA) or the constant temperature (CTA) mode. The probe itself was a DISA, model 55D50, gold plated general straight prong, Pt-plated tungsten wire probe, calibrated for low velocities (under 1 m/sec) at the exit of a uniform velocity profile nozzle, the flow into which was measured with a Foxboro, model E13DM, differential pressure cell with integral orifice. The Foxboro flowmeter was in turn calibrated with a GCA/Precision Scientific wet test meter. For velocities greater than 1 m/s, the anemometer was calibrated in a miniature wind tunnel equipped with a venturimeter and micromanometer. The bridge circuit used with the anemometer for CTA operation was a DISA Standard Bridge, model 55M10. The output from the bridge was fed to a DISA integrating voltmeter in order to average out the fluctuating component of velocity.

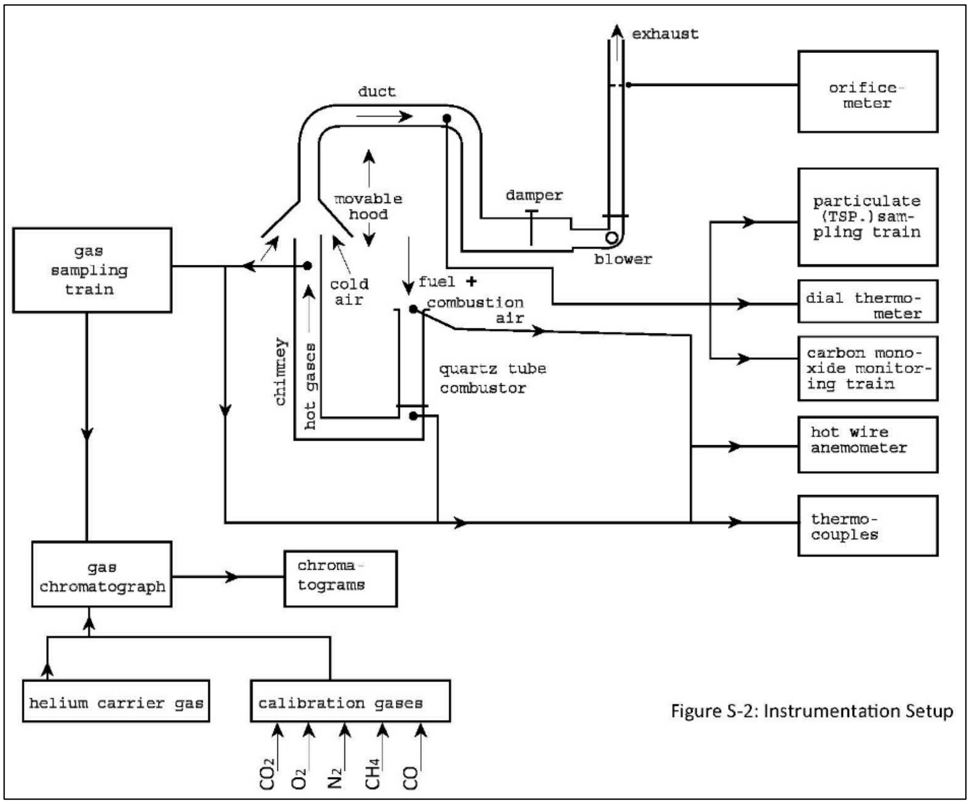

Figure S-2: Instrumentation Setup

Exhaust gases were sampled for analysis using the gas sampling train shown in Figure S-3. The sampling consisted of withdrawing, conditioning, and storing flue gas samples taken at different times during a burn. Samples introduced to a gas Chromatograph (GC) must be cool, dry, and free of particulates. Flue gas samples were extracted from the gas stream with a 6.4 mm dia. (1/4"nominal dia. (3/16" I.D)) copper tubing probe with its entrance facing downstream in order to prevent particulate accumulation and clogging (Cooper and Rossano, 1974). A 2 m length of 6.4mm dia. copper tube condenser provided initial cooling of the hot sampled exhaust gases. After passing through the water trap to remove condensate and a 37 mm SKC Inc., type A, glass fiber filter to remove particulates, the gases were bubbled through a fritted glass bead bubbler immersed in an ice bath. After further filtration by a filter of same make, the gases were passed through a 450 mm long drying tube containing calcium sulfate. The gas mixture was then ready to be collected in gas sample bags for gas chromatograph analysis. For this purpose, the mixture stream was led to a ten-port gas sampling manifold. Each port had a separate needle valve and each was connected to a lockable 1 liter, 5 layered gas sample bag with silicone rubber septum. The suction pump used in the train was a Gilian Model HFS 113, constant flow, dual diaphragm, sampler pump, with a built-in, 0 to 4 lpm rotameter. The train also was provided with a manometer for leak detection and measurement of pressure drop in the lines of the train during operation. The flue gas samples obtained in the gas sample bags were analysed using a Fisher Hamilton Gas Partitioner (model 29), for CO, CO_2, O_2, N_2 and CH_4. This device has two columns in series; a 6ftx1/4" aluminum tube packed with 30% Di-2-ethylhexylsebacate (DEHS) on 60-80 mesh Chromosorb P for detecting CO_2, and a 6.5.ftx3/16" aluminum tube packed with 40-60 mesh molecular sieve for CO, O_2, N_2 and CH_4 detection. Calibration was carried out using a multicomponent mixture standard gas from Scott Specialty Gases, California.

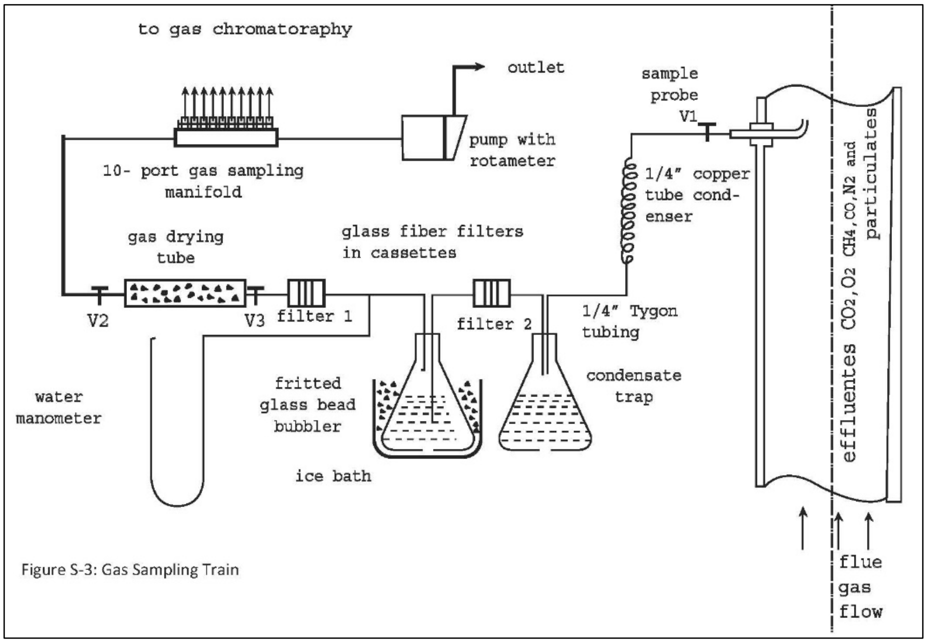

Figure S-3: Gas Sampling Train

The exhaust particulate sampling system had continuous carbon monoxide monitoring setup. Aerosol was withdrawn isokinetically[1] with a 6.4 mm dia. probe inserted in the diluted flue gas stream in the galvanized iron duct. A dial thermometer was put in the duct beside the probe to measure the temperature of the diluted flue gas at this point. The aerosol was drawn through the sensing chamber of a GCA corporation, light scattering, nephelometric[2] type aerosol monitor, model PDM-3, having a range of 0 to 100 mg/m^3 and a precision of ±0.03 mg/m^3. The Glasrock Plastics 37 mm filter cassette placed immediately after the monitor collected particulates on a 37 mm SKC, type A, glass fiber filter, enabling calibration of the monitor by gravimetric method. The filter, when not used for calibration, served to protect the vacuum pump (Gilian, model HFS 113). The filtered gas, after passing through the pump is passed through a 250 ml mixing chamber to dampen oscillations in CO concentrations. It then enters the detector cell of a continuous CO monitor (Gastech Inc. model C0-82). The detector is of the electrochemical cell type and has a range of 0-2000 ppm. The instrument was calibrated within ± 5 ppm using 203 ppm CO standard gas obtained from Airco Industrial Gases. The electrical signal output from the CO monitor was averaged by a DISA, type 52B30, true integrator. The integrated output could be either displayed on a digital voltmeter (Hewlett Packard, model 3438 B) with a resolution of 0.1 mV on a 2 volt scale or fed to a strip chart recorder (Linear Instrument Corp, model 142) with a resolution of 20 mv on a 1 volt scale.

[1] Isokinetic sampling involves matching the direction or the sampling nozzle towards the flow stream, and keeping the nozzle intake velocity the same as the stream velocity. Otherwise, the momentum or the heavier particulates causes an unrepresentative amount of TSP to enter the nozzle. The two velocities were matched by adjusting the flow rate through the pump as measured by the inbuilt rotameter.

[2]Nephelometric type monitor senses the combined light scattering from the population of particles present within its sensing volume whose dimensions are large compared to the average separation between the individual particles.

Supplement 3: Stratified Gasifier/Combustor Zones

The operation of the burner consists of three phases; start-up, steady state, and burn-out. Although minor observations were made during the start-up and burn-out, the major part of this study was concerned with the steady state portion of the burn. The start-up phase was comprised of an ignition stage and a warm-up stage. The ignition of the downdraft burner can be somewhat difficult since the fuel must be ignited from below. Details of the lightoff procedure can be found in Supplement 4.

Note was made of the various parts of the bed as illustrated in Figure S-4. There was no visual indication of the biomass drying zone. Likewise, a pyrolysis zone could not be observed as a separate zone. The zone of flaming pyrolysis described by Reed (1983) for his stratified downdraft gasifier could easily be distinguished as small regions of bright· flames with each region encompassing a pyrolysing 37 mm (1.5") long, cylindrical fuel particle. The char reduction zone could be observed as a dull glowing zone similar in appearance to burning charcoal. The inert char zone was seen to be a black region extending down to the grate.

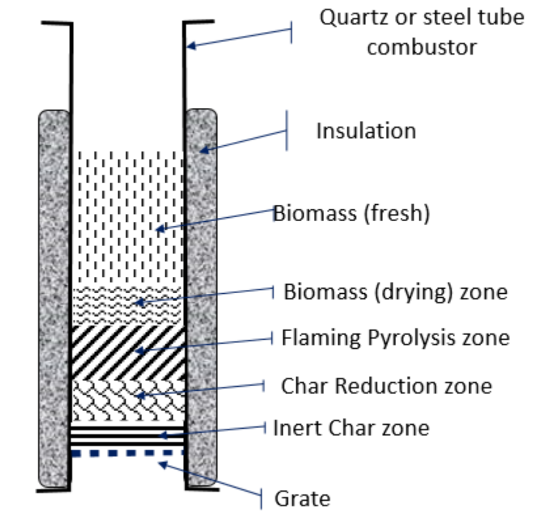

Figure S-4: Zones in the Stratified Downdraft Combustor

Supplement 4: Lightoff Procedures

The lighting up of the downdraft combustor was at times been quite vexing. Five to six pieces of cow dung fuel dipped in kerosene were put on the grate. More cow dung fuel (not dipped in kerosene) were added until the fuel height in the quartz tube was seen to be 150 mm. Less fuel height at this stage caused the flame to updraft vigorously. The blower fan was started and the hood raised to its maximum height to decrease suction on the quartz tube and thus avoid blowout of the flame. The quartz tube was raised inside its sliding clamp guide with a gloved hand and the flame of a bunsen burner using propane gas was applied to the underside of the grate. Having started the downdraft flame, the quartz tube was held about 25 mm above the quartz-steel joint for 3-4 minutes until the fierceness of the kerosene fed flames died down. As seen through the transparent sides, lowering the quartz tube at this time caused an imbalance between the generation of pyrolysis gases and the consumption of it in the flames. There was apparently a mismatch here between the generation and consumption of volatiles. The gap between the quartz tube face and the steel face was very critical at this point. Slight movement of the quartz tube caused the flame to extinguish. Approximately 2 minutes later, the hood was lowered to its working position of 775-825 mm on the wall scale. This corresponded to approximately 7.5 to 12.5 cm/s primary air velocity through the combustor as measured by the hot wire anemometer. The flame inside the quartz tube was now stable.

References

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Cooper, H. B. R. Jr., and Rossano, A. T. Jr., 1974, "*Source Testing for Air Pollution Control",* McGraw Hill Book Company, 139-140