integrated energy systems

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DEVELOPMENT AND TESTING
OF AN AUTOMATED WOOD-
BURNING HEATING SYSTEM

FINAL REPORT

Appropriate Technology Program
Grant No. DEFG 4480R/10156

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Submitted to:

Appropriate Technology Program
U.S. Department of Energy
1655 Peachtree St., NE
Atlanta, GA 30367

May 1981

MASTER

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*Not
included*

removed

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INTRODUCTION

Integrated Energy Systems is pleased to report that the project "Development and Testing of an Improved Wood Combustion System, Applying a Tunnel Burner", sponsored under DOE's Appropriate Technology Program, has been successfully completed. The tunnel burner integrated in a boiler heating system has proven to be very efficient, very clean, and safe to operate. Besides the testing of the prototype, we were able to redesign and fabricate a 2nd generation tunnel. In order to get to the threshold of commercializing the equipment, the system needs to be adapted to one or two ideal applications and equipped with the appropriate controls. This will hopefully happen during the next year.

The photographs on the following page highlight various aspects of the project.

~~Handwritten text, possibly "The end of the world"~~

~~Handwritten text, possibly "The end of the world"~~

~~Handwritten text, possibly "The end of the world"~~

1. WORK PERFORMED

The work performed between April 1980 and April 1981 is summarized in Table I, "Project Summary". A prototype tunnel burner has been integrated into a prototype boiler heating system. This installation has been tested for efficiency, temperatures, fuel parameters, and emissions. Virtually all the data were used in one way or another to redesign the tunnel burner or make adjustments on other parts of the system. The second generation tunnel burner has been fabricated. A patent search and preliminary investigations for commercialization were performed. Two technical papers have been written on wood combustion parameters including the air pollution emissions. Two successful demonstrations took place, where DOE and NC Energy Division officials and the press were informed about the project.

Table I. Project Summary.

Date	Work Performed	Major Events
April - May 1980	Purchase materials - boiler - hopper/auger Site preparation - building of pole shed - building of boiler base Prepare measurement plan - components - equipment - schedule	
June 1980	Calibrate auger - measure rpm/feed rate ratio - adjust gear motor and pulleys Order high temperature measurement equipment	

Table 1. (cont.)

Date	Work Performed	Major Events
June 27, 1981	First adjustments made on fuel intake pipe in tunnel	First firing with new boiler set-up
June 29, 1980		First contact with David Rabin, patent attorney
July 1980	Last adjustments on pellet feed to get ideal flow	
June 23, 1980	Calibrate water flow through boiler. Testing of high temperature measurement equipment & wiring and built housing for readout instrument	Second firing, combustion tests, response tests
August 1980	Finalize location for temperature readings in tunnel and on outside surface, stack, and boiler water. Visit to DOE, Atlanta requesting help on patent questions and commercialization	
August 20, 1980		Third firing, temperature measurements; established temperature profile

Table 1. (cont.)

Date	Work Performed	Major Events
September 9, 1980	Several more testing days to get temperature profiles	Demonstration of prototype to DOE and State officials and press
September 10, 1980		Pulling fuel samples after 2 hours of operation
September 15, 1980	Alteration to tip of tunnel to add ash dump	Demonstration to Dr. James Bresee, NC Energy Institute and Pullman-Woodex
September 28, 1980		Last test for logistics of start-up and burn-out
September 30, 1980	Disassembling of installation	
October 1, 1980	Preparation of schedule for emission tests. Received fuel analysis tests.	Moving of total installation to EPA's IERL at Research Triangle Park
October 27, 1980	Testing of tunnel burner in 13 different fuel rate and fuel-to-air ratio set-ups (total of 6 hours). Components measured: O ₂ , CO ₂ , CO, NO, NO _x , HC, smoke, SO _x , temperature	

Table 1. (cont.)

Date	Work Performed	Major Events
October 29, 1980	Testing of tunnel in 12 different fuel rate and fuel to air ratio set-ups (total of 7 hours)	
November 1980	Evaluation of first emission data; deciding at which points to test for particulates and POMs	
November 7, 1980	Additional testing of tunnel at 8 different fuel rates and fuel-to-air ratio set-ups (total of 6 hours)	
November 12, 1980	Sampling of particulates with Method 5 at one of selected set-ups	
November 14, 1980	Sampling of particulates with Method 5 at other selected set-up Disassembling of installation at EPA and transporting it back to IES test site	
November 18, 1980	Redesign of tunnel and scale-up to 200,000 BTUs/hr	

Table 1. (cont.)

Date	Work Performed	Major Events
December 2, 1980		Ordered patent search from David Rabin
December 10, 1980	Preparation of paper to be published in hard cover biomass conversion book by the American Chemical Society	
February 18, 1981	Received compiled data from EPA. Adjustments on 2nd generation tunnel to fit existing boiler	
April 10, 1981	Received results of patent search	
May 4, 1981	Wrote review letter on patent search	Fixing of 2nd generation tunnel burner

II. RESULTS

The most important results of the A.T. project are:

- the finalized tunnel burner design
- high combustion efficiency
- low air pollution emissions

The improved design of the tunnel is shown in Appendix G. The major improvements over the prototype are:

- ash drop incorporated in the tunnel burner design
- exchangeable back plate with auger extension pipe
- increased gap between concentric tunnel walls
- adjustable combustion air hole pattern, making one tunnel design adaptable to fuels of different composition (moisture, volatiles, grain size, energy density)

The main results of the combustion and emission tests are summarized in Table II. In order to appreciate how spectacular the air pollution emission results really are, Table III shows emission rates in milligrams per mega-joule of various combustion equipment and fuels. The comparison of the emission testing results with emission rates of other small wood combustion devices shows that the tunnel burner has particulate emissions 8 to 10 times lower than wood stoves and fireplaces. The POM results were below the detectable limit of the analytical method used.

Comparing the tunnel burner with gas, oil, and coal burners shows that particulate emissions of the tunnel burner are of the same order of magnitude as oil and gas burners and well below coal burners. Hydrocarbon emissions from the tunnel burner are below those of oil and gas. This gives us an indication that we are able to completely burn the wood gases which are produced in the back part of the tunnel. CO is not quite at the level of oil and gas burners. But CO proved to be a very sensitive component and changed parallel with the smoke levels which were also measured.

The measurement protocol from the particulate sampling tests are attached in Appendix C and the POM results in Appendix D.

Table II. Summary of Particulate Matter Test Run at EPA's IERL.

	Test run #1 (IESTB - 111280)	Test run #2 (IESTB - 111480)
O ₂ , average %	10.08	11.03
CO ₂ , average %	12.2	11.5
CO, average, ppm	175	105
NO ppm	70	67
NO _x ppm	72	70
HC ppm	2.0	2.0
Smoke, average	7.6	6.97
TSP mg/m ³	49.7	38.1
POMs, µg/m ³	<0.004	<0.008
fuel feed rate, lbs/hr	4.82	4.88
burner capacity, BTU/hr	38,560	39,040
stack temp., °F	384	408
boiler performance, Δ°F (at 1.5 GPM)	28	34
comb. efficiency, %	85.6	83.6
overall system efficiency, %	54	65

Table III. Emission Rates (in mg/MJ) of IES Tunnel Burner and Other Equipment and Fuels.

	CO	HC	NO _x	Particulates	POMS
<u>Wood</u>					
Tunnel Burner	56-95	1.96-2.0	40.7-42.8	18.4-24.7	<0.000002
Fireplace ¹	1,100	1,100	130	100-210	2.6-3.8
Baffeled Stove ¹	6,200-16,000	150	20-60	170-510	22.3-39.1
Unbaffeled Stove ¹	6,800-21,000	20-220	10-40	110-460	19.8-33.5
<u>Gas</u> ²	8.6	4.3	34.4	2.15-6.45	
<u>Oil</u> ²	17.2	4.3	68.8	6.02	
<u>Coal</u> ²	1,488	331	51.6	331	

¹ R. E. Hall and D. G. De Angelis, EPA's Research Program for Controlling Residential Wood Combustion Emissions, J. APCA 30(8), 1980, 862-867.

² Compilation of Air Pollutant Emission Factors, US EPA, 3rd edition, Supplement no. 9, July 1979.

III. RESPONSE

The response to the project was very good. The demonstration on September 4, 1980 was a complete success. All three local TV stations covered the event. The air pollution aspect and the automatic feed mechanism seemed to be the most highly visible advantages of the tunnel burner system. Also the possibility of using the tunnel burner as a retrofit option on oil and gas fired systems seemed to have created a good response.

There was one other aspect which has impressed many of the people who have seen the installation; the simplicity of the design. This fact encouraged us to keep the design simple; even some of the necessary improvements threatened to complicate the design.

Press releases are attached in Appendix A and newspaper clippings in Appendix D.

IV. ACKNOWLEDGEMENTS

We would like to thank all of the people who have given us their full support throughout the whole project. And we hope they will support us throughout the commercialization phase as well. Special thanks goes to Louis F. Centofanti, Charles Feltus and Pat Jeanson at the Regional Office of DOE in Atlanta, to Bob Powell at the NC Energy Division, to Carsie Denning at the NC Board of Education and to Warren Rock at the NC Department of Agriculture.

APPENDIX A
PRESS RELEASES FOR
GRANT AWARD AND
TUNNEL BURNER DEMONSTRATION

integrated energy systems

FOR IMMEDIATE RELEASE, 2/14/80

GRANT AWARD FOR INNOVATIVE WOOD COMBUSTION SYSTEM

Motivation Leading to Invention and Project

It is in the nature of consulting work to lead into new ideas and concepts. Often the appropriate hardware is not to be found on the market. Out of such experiences over the last 3-4 years, we realized that solid fuel heating systems for replacement of oil and gas fired systems do not exist in an appropriate form. In our opinion, "appropriate" means a system which could feasibly be retrofitted to existing oil and gas fired boilers and furnaces, and which would supply heat with the same level of comfort as oil or gas systems.

There was also the tremendous potential we saw in wood as a renewable energy source. North Carolina's forest product industry generates large quantities of wood waste and the thousands of acres of unmanaged forests in the state could be upgraded by thinning. This thinning process could produce large quantities of wood fuel.

Another motivating circumstance for us was the fact that small and medium sized solid fuel heating systems are quite often subject to air pollution problems. Our new wood/solid fuel combustion system will help to reduce air pollution from such installations.

The main contribution for this invention came from Werner Martin, who is our air pollution engineer. It is characteristic of our company that interdisciplinary teamwork is not only creating new ideas, but is also successful in realizing them. Besides a degree in air pollution engineering, Werner Martin also has a degree in forestry sciences which allows him to implement a whole systems approach in the wood-energy management area.

Project Description

The project will develop an improved wood combustion system. The key element, the tunnel burner, and the conceptual idea of the continuous automated combustion system have been developed. Thus, at this point we need to integrate the fuel charging system with the burner and our test boiler, then test and monitor their performance. The final product of the project will be a tested prototype of a complete wood combustion system with a burner/heat exchanger and an automated fuel (chips, pellets, etc.) feed system. The heat exchanger can be an existing oil or gas fired boiler/furnace. The scale of the unit is appropriate for institutional, commercial and residential systems.

The concept behind this system is one in which we believe strongly,

and is very different from conventional types of combustion equipment. It takes into account all the special features of biomass fuels. The high temperatures, slow preparation phase prior to combustion, and the slow reaction time of solid fuels for variation in heat production, are all considered in the design.

The burner/heat exchanger concept will make use of fuel wood which is either processed waste wood (e.g. pellets) from the wood-working industry, chips, or hogged fuel wood from forest residues. Thus, waste fuels will substitute, in most cases, for oil. This burner/heat exchanger concept will, besides replacing oil, conserve wood fuel and reduce air pollution for the following reasons:

1. better fuel/air ratio control;
2. higher combustion temperature;
3. longer retention time for fuel;
4. automated feed control allows immediate adjustment of firing rate to heat demand.

The advantages of the first three features are the result of moving the fuel out of the heat exchanger (furnace/boiler) into a relatively small, well controllable tubular containment tunnel. The tunnel is the central piece of our invention. Preheated combustion air is forced into the tunnel where wood fuel is pushed through by a conveyor system.

Merits and Applications of Expected Project Results

In any application, our project's technology would beneficially affect the environment in two ways.

1. Increase the market for wood waste materials now being deposited in land fills or burned in the open air, by processing them into pellets for example, and using them as an energy source. Increased use of low quality wood as a fuel will create an incentive for better forest management which will mean the enhancement of the functions of our forests, such as soil protection against erosion, groundwater protection and maintenance of recreational value.

2. The wood combustion in this flow-through burner system is expected to be much cleaner (less air pollution) than in current systems. Where a wood combustion system substitutes for oil or gas there may be an increase in particulate emissions, but a reduction in NO_x and SO_x . To prove this is one of the objectives of our planned test.

Possible applications are mainly seen in small and medium sized heating systems. Schools, office buildings, and private residences are likely to be the best applications. But drying of agricultural and forest products like tobacco and wood could also benefit from this new system. We will be looking for application sites as soon as we have optimized the system and can confirm the advantages we attribute to our new improved wood burning concept.

Who is IES, Inc?

Integrated Energy Systems, Inc. (IES), has specialized in energy design, planning and engineering since 1976, making us a veteran in this field. Prior to forming IES, our principals had many years experience in air pollution study, HVAC engineering and in environmental planning in North Carolina, other parts of the U.S. and abroad.

As the company's name indicates, we take a systems approach to energy production and use. Thus, we offer a wide range of services in this field:

- architectural design of energy efficient structures;
- engineering design of energy efficient systems;
- renewable energy sources management (biomass);
- air pollution impact analyses of energy conversion processes.

James B. Hunt, Jr.
Governor

D. M. Faircloth
Secretary

NORTH CAROLINA
DEPARTMENT
OF COMMERCE

James E. Gibson, Jr.
Director

ENERGY DIVISION
(919) 733-2230

August 29, 1980

TO THE CAPITOL PRESS CORPS:

You are cordially invited to join Dr. Lou Centofanti, Southeastern Regional Representative for the U. S. Department of Energy at the unveiling and test demonstration of a new wood combustion "Tunnel Burner" on Thursday, September 4, 1980, at 9:00 a.m. on Loop Road in Carrboro, N.C. (see map attached on back). Directional signs will be posted beginning at the Jones Ferry Road exit from 15-501 Bypass.

The "Tunnel Burner", an advance in wood-burning technology, was developed by Integrated Energy Systems, a Chapel Hill based consulting firm, under a \$18,000 grant from the Regional U. S. Department of Energy office headed by Dr. Centofanti to build and test a model burner.

Once testing on the burner is completed a prototype will be built for commercial production. The burner could be used in homes, schools and office buildings and could have some industrial applications, namely, in drying of tobacco or wood.

The model burns pellets made from wood presently going to waste, uses a conveyor system to feed the fuel into the burner, from which the heat is expelled into a furnace. The system produces less polluting smoke than conventional wood heaters and burns at higher temperature's than under conventional wood burning conditions.

Dr. Centofanti and Werner Martin, inventor of the "Tunnel Burner" will be on hand at the testing site to answer any press queries.

For additional technical information, please contact Mr. Werner Martin at: (919) 942-2007, for questions relating to Dr. Centofanti's visit, please contact: Lillie Murdock, N.C. Energy Division (919) 733-5078.

August 29, 1980

Dear

You are cordially invited to attend the demonstration of our prototype of an automated wood pellet combustion system on Thursday, September 4, 1980. The purpose of the demonstration is to present IES development work in the area of wood combustion systems to Department of Energy (DOE) officials. DOE has supported our work through a grant under the Appropriate Technology Program.

The demonstration will take place at 9 a.m. at the site indicated on the attached map.

Sincerely,

Werner Martin

WM: kb

FOR IMMEDIATE RELEASE 9/4/1980

DEMONSTRATION OF INNOVATIVE WOOD
COMBUSTION SYSTEM FOR U.S. DEPARTMENT OF
ENERGY AND N.C. ENERGY DIVISION OFFICIALS

Important Visitors

Dr. Louis F. Centofanti, U.S. Department of Energy (DOE), representative for Region IV (South), from Atlanta, took the occasion of visiting one of the projects sponsored under DOE's Appropriate Technology Program. With him were Jim Gibson, Director of the N.C. Energy Division, and many of the officials involved in North Carolina's wood energy development efforts. Integrated Energy Systems, Inc. took the opportunity to present its capabilities in the area of wood combustion testing and systems development.

Principles Involved in New Automated Wood Combustion System

As wood becomes a more and more popular fuel again, many old wood combustion systems like cast iron stoves and dutch ovens are being revived. The old problems of wood heating, however, remain. They are: high maintenance, slow reaction time, low heat storage capabilities, and incomplete combustion. Most of the solutions for clean, efficient combustion are presently sought by gasification, liquifaction, and by rather complex technologies like fluidized bed combustion. Integrated Energy Systems (IES) has in the past few months developed a piece of equipment which is relatively simple, but incorporates new and old principles of gasification and combustion. The prototype was developed under a DOE grant and has demonstrated high efficiency, low air pollution, and very short reaction times to load changes. The most important principles incorporated in the new combustion system are outlined below:

A. Horizontal Fuel Flow

In most existing solid fuel combustion systems the fuel flow is vertical rather than horizontal. Fuel is brought into

CONVENTIONAL TUNNEL BURNER

the combustion zone either from underneath or above.

The tunnel burner uses a horizontal fuel flow, allowing better stratification of the combustion process.

B. Separation of Combustion Chamber and Heat Exchanger

Because of the enormous difficulties experienced in reaching complete combustion in an environment of relatively cold boiler and furnace walls, the new system separates combustion from the heat extraction process. IES believes that by separating the two, the combustion chamber and the heat exchanger can be optimally designed. Also the tunnel burner becomes a combustion system well suited for retrofitting existing boilers, furnaces, and kilns from liquid and gaseous fuels to wood or other solid fuels.

C. Minimize Size of Combustion Chambers

The tunnel burner through its flow-through concept allows a small cross-section combustion chamber. This gives a better chance of having equally good combustion conditions throughout the whole combustion zone.

The tubular structure eliminates less controllable corners and provides an ideal environment for the flow of fuel and combustion gases.

D. Preheating of Combustion Air

Preheating the combustion air allows the high combustion temperatures necessary to burn wood efficiently. At the same time, stress on the metal from those high temperatures can be reduced by cooling the inside wall of the tunnel.

E. Ideal Fuel-Air Mixing

Turbulence is a very important factor in all combustion processes. The tunnel

CONVENTIONAL TUNNEL BURNER

AIR INTAKE JETS

burner utilized small air jets for bringing combustion air from above and below into the fuel bed. The pattern of the air holes and the speed of the incoming combustion air are both carefully selected in order to achieve ideal turbulence.

F. Fixed Ratios Between Fuel Characteristics and Tunnel Dimension

For a wide variety of solid fuels (wood, peat, coal, crop waste, etc.) the basic design of the tunnel can be used. Parameters characterizing fuels will, however, effect the dimensions of the tunnel.

Seeking First Applications

A. Hydronic Heating and Domestic Hot Water Systems in School, Apartment, and Office Buildings

Systems in the range of 150,000 to 400,000 BTU's/hr. output presently fired with oil or gas are good candidates for a tunnel burner system. Critical constraints for retrofits are: availability of fuel storage space and expected remaining life-time of existing boiler.

Tunnel burners could be made available for burning wood pellets within approximately 3 months. The cost for the complete system will be around \$20/thousand BTU's output capacity. Adjustment costs on site will vary from application to application. In larger boilers several individual burners of about 150,000 BTU's/hr. will be attached to the existing system.

Wherever automatic systems are necessary, the tunnel burner will have its chance.

B. Drying Processes (Tobacco, Corn, Peanuts, Minerals)

Drying installations like tobacco barns, other crop drying equipment, kilns for the drying of lumber, minerals, and even for pottery could benefit from the tunnel burner.

The idea is to produce a mobile system for the farmer so he can move it around for various uses.

The wooden fuel in such cases can be either in the form of pellets or a hogged biomass fuel. The adaptation work to use wood chips in the tunnel burner should get underway soon.

IES has not the funds available to start working on it at the present time. But for applications in the agricultural sector, it seems important to give consideration to the biomass fuel most easily and cheaply available to the farmer.

INTEGRATED ENERGY SYSTEMS, INC. has specialized in energy design, planning and engineering since 1976. Besides air pollution studies and wood burning technology, IES is also involved in solar home design, and environmental planning. We have recently completed energy audits of over 300 schools around North Carolina, currently heating with gas or oil, where the Tunnel Burner system would have tremendous advantages to offer.

APPENDIX B

EPA'S POM SPOT TEST RESULTS

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
RESEARCH TRIANGLE PARK
NORTH CAROLINA 27711

DATE: January 12, 1981

SUBJECT: Level 1 Organics Analysis of Samples from Wood Chip Burns
of November 12 to November 14, 1980.

TO: Robert Hall
IERL-CRB

FROM: Ray Merrill and Ray Steiber

The samples received for analysis consisted of 2 XAD-2 charges and 2 filters with appropriate blanks. Preparation and analysis of these samples was carried out using standard Level 1 procedures. The XAD-2 resin from the organics traps was decanted into glass thimbles and extracted for 24 hours in a soxhlet extractor with methylene chloride. The resulting samples were then concentrated to 5 ml (IESTB 111480) and 10 ml (IESTB 111280) respectively. Microliter portions of each sample were subjected to TCO analysis by GC-FID, while another portion was transferred to pre-weighed weighing pans for gravimetric determination. In addition, the two filter samples were soxhlet extracted and also subjected to gravimetric analysis.

Subsequent to the TCO and grav determinations, the two XAD samples were subjected to the spot test for PAH's. 1.0 μ l portions were sensitized with ultra high purity naphthalene and then activated with UV light at 254 nm. Comparison with the naphthalene blank revealed the presence of no PAH's in concentrations above the lower limits of detection (1-10 picograms per microliter).

The attached sheet presents the results of all the above analyses in tabular form.

CRB WOOD CHIP BURNS ANALYSES

Total TCO

IESTB111280XAD Extract	1.3mg
IESTB111480XAD Extract	0.5mg

Total GRAV

IESTB111280XAD Extract	2.00mg
IESTB111480XAD Extract	0.32mg
IESTB111280 Filter #1	6.20mg
IESTB111480 Filter #3	0.30mg

Total GRAV + TCO

IESTB111280XAD Extract	3.3mg
IESTB111480XAD Extract	0.82mg

Spot Test

IESTB111280XAD Extract	BLD*
IESTB111480XAD Extract	BLD*

*Below limit of detection (1-10 picograms per microliter)

The above data represents the total amount found in each sample; we were unable to calculate in terms of g/ft³ because we were not provided with the sampling data.

APPENDIX C

EPA'S TSP AND GASEOUS COMPONENT
EMISSION TESTING RESULT

PLANT EPA - CRB

DATE 11-14-80

RUN NO. TESTB-11/420

CONTAINER NUMBER	WEIGHT OF PARTICULATE COLLECTED = gm		
	FINAL WEIGHT	TARE WEIGHT	WEIGHT GAIN
<u>B</u>	<u>58.6554</u>	<u>58.6198</u>	<u>0.0356</u>
<u>D</u>	<u>138.9270</u>	<u>138.9199</u>	<u>0.0071</u>
TOTAL			<u>0.0427</u>

1.12

~~1.12~~ m³

- 37.5 m³
38.1 m³

Dick #3
Beaker X

	VOLUME OF LIQUID WATER COLLECTED	
	IMMINGER VOLUME ml	SILICA GEL WEIGHT g
FINAL	<u>170</u>	<u>208</u>
INITIAL	<u>100</u>	<u>200</u>
LIQUID COLLECTED	<u>70</u>	<u>8</u>
TOTAL VOL. COLLECTED	<u>78</u>	<u>63</u> ml

4/ 59
2nd day 111

* CONVERT WEIGHT OF WATER TO VOLUME BY DIVIDING TOTAL WEIGHT INCREASE BY DENSITY OF WATER. (1 g/ml):

$$\frac{\text{INCREASE g}}{(1 \text{ g/ml})} = \text{VOLUME WATER ml}$$

Figure 5-3. Analytical data.

Pump, nozzle & filter holder rinsed in methanol.
XRD-2 rinsed in methylene chloride

OPERATOR Butts
 DATE 11/14/50
 RUN NO. TEST 13-111480
 SAMPLE BOX NO. _____
 METER BOX NO. _____
 METER Δ Hg _____

TUNNEL DATA
 STACK DIA. = 6"
 SAMPLE POINT 3 1/2' IN
 VELOCITY 170 FT/min

AMBIENT TEMPERATURE 20°F
 BAROMETRIC PRESSURE 30.28
 ASSURED MOISTURE, % 9.15% (Actual)
 HEATER BOX SETTING 2-2°F
 PROBE LENGTH, m. 3' STAINLESS
 NOZZLE DIAMETER, in. .50
 PROBE HEATER SETTING 70

SCHEMATIC OF STACK CROSS SECTION

TRAVERSE POINT NUMBER	SAMPLING TIME (c) min.	STATIC PRESSURE (P _s) in. Hg	STACK TEMP. (T _s) °F	VELOCITY HEAD (Δ P _s)	ORIFICE PRESSURE DIFFERENTIAL (Δ P) in. H ₂ O	GAS SAMPLE VOLUME (V _m) cc.	GAS SAMPLE TEMPERATURE AT DRY GAS METER		SAMPLE BOX TEMPERATURE °F	TEMPERATURE OF GAS LEAVING LAST IMPINGER °F
							INLET (T _{m in}) °F	OUTLET (T _{m out}) °F		
-	1.5		340		0.27	307.1	80	80	250	65
-	2.0	3	340		0.24	313.69	82	100	250	65
-	2.5	4	340		0.24	315.46	88	108	250	63
-	3.0	4	340		0.24	318.24	92	114	250	65
-	4.0	4.5	340		0.24	321.03	98	118	250	65
-	5.0	5	340		0.24	322.83	100	120	250	68
-	6.0	5.5	340		0.24	326.64	104	122	250	65
-	7.0	6	340		0.24	329.45	106	124	250	64
-	8.0	7	340		0.24	332.30	108	126	250	64
-	9.0	8	340		0.24	335.13	110	126	250	64
-	10.0	9	340		0.24	337.93	110	128	250	64
-	11.0	10	340		0.24	340.75	110	130	250	65
TOTAL		12	340		0.24	343.59	110	130	250	66
AVERAGE	14.0	10.5	340		0.24	346.42	112	130	250	66
15.0	15.0	11	340		0.24	350.12	112	130	250	66

40.15
 20/PT

15.0 →

119.7

RUN # IEST13-111480

O ₂	11.03%
CO ₂	11.5%
CO	105 PPM
NO	67 PPM
NO _x	70 PPM
HC	2.0 PPM
STACK TEMP.	408 °F
SMOKE	6.97 (Avg)
ΔT HEAT EXCHANGER	34 °F
HEAT EXCHANGER FLOW	1.5 GPM
BURNER FEED RATE	$0.263 \text{ RPM} \times 140 \text{ gms./r} = 4.88 \text{ Lbs/Hr.}$

TEST B - 111480

$$V_{M_{STD}} = \frac{\text{Dry Gas Sample Volume}}{39.58 \times 1.138 \times 1} \left(\frac{769.112 + \frac{6.096}{13.6}}{302.27} \right) =$$

$$4390 \left(\frac{769.5602}{302.27} \right) = 1.118 \text{ m}^3$$

$$V_{M_{STD}} = 39.482 \text{ m}^3$$

$$W_{STD} = \frac{\text{Volume of water vapor}}{0.01333 \times 78} = 1.03974 \text{ m}^3$$

$B_{WS} = \text{Stack Gas Moisture}$

$$\frac{1.118}{1.118 + 1.03974} = 9.15\%$$

PLANT EPA - CR13

DATE 11/23/80

RUN NO. IES-111280

CONTAINER NUMBER	WEIGHT OF PARTICULATE COLLECTED in GMS		
	FINAL WEIGHT	TARE WEIGHT	WEIGHT GAIN
1 ~~4~~	58.9540	58.9071	0.0469
2 ~~5~~	143.8943	143.8845	0.0098
TOTAL			0.0567

FILTER -
BEAKER -

1.14 ³

49.7 mg/m³

	VOLUME OF LIQUID WATER COLLECTED	
	IMPINGER VOLUME ml	SILICA GEL WEIGHT g
FINAL	173	204
INITIAL	100	200
LIQUID COLLECTED	73	4
TOTAL VOL. COLLECTED	77	ml

Final
1st imp - 70
2nd imp 103
173

* CONVERT WEIGHT OF WATER TO VOLUME BY DIVIDING
TOTAL WEIGHT INCREASE BY DENSITY OF WATER. (1 g/ml):

$$\frac{\text{INCREASE g}}{(1 \text{ g/ml})} = \text{VOLUME WATER ml}$$

Figure 5-3. Analytical data.

Note: filter and filter holder rinsed in methanol,
XAD-2 rinsed in methylene chloride.

OPERATOR W. T. T.
 DATE 11-12-80
 RUN NO. TEST 3 - 11280
 ANGLE BOX NO. _____
 METER BOX NO. _____
 METER Δ Hg _____

STACK DIA. - 6"

SAMPLE
 POINT - 3 1/2 IN

BAROMETRIC PRESSURE 30.25
 ASSUMED MOISTURE, % 4.17% (actual)
 HEATER BOX SETTING 250°F
 PROBE LENGTH, in. 3'
 NOZZLE DIAMETER, in. .50
 PROBE HEATER SETTING 50

SCHEMATIC OF STACK CROSS SECTION

TRAVERSE POINT NUMBER	SAMPLING TIME (c) min.	Vacuum	STACK TEMP. (T _s)°F	VELOCITY HEAD (Δ P _s)	ORIFICE PRESSURE DIFFER- ENTIAL (Δ H) In. H ₂ O	GAS SAMPLE VOLUME (V _s)cc. 3	GAS SAMPLE TEMPERATURE AT DRY GAS METER		SAMPLE BOX TEMPERA- TURE °F	TEMPERA- TURE OF GAS LEAVING LAST IMPELLER °F
		STATIC PRESSURE (P _s) in Hg					INLET (T _m in) °F	OUTLET (T _m out) °F		
	0	Start				269.06				
-	5	2.0	320		.20	270.66	80	84	250	69
-	15	2.0	320		.20	272.77	82	94	250	69
-	25	3.0	320		.20	275.37	86	104	250	69
-	35	3.0	320		.20	277.20	90	110	250	68
-	45	3.0	320		.20	280.36	94	114	250	69
-	55	4.0	320		.20	282.91	98	118	250	68
-	65	4.0	320		.20	285.47	100	120	250	69
-	75	5.0	320		.20	288.04	104	120	250	70
-	85	6.0	320		.20	290.63	106	122	250	72
-	95	7.0	320		.20	293.16	108	122	250	69
-	105	8.0	320		.20	295.73	110	124	250	69
TOTAL	115	9.0	320		.20	298.32	110	126	250	69
-	125	9.0	320		.20	300.90	112	128	250	68

~~TURNER~~

TRAVERSE POINT NUMBER	SAMPLING TIME (e) min.	<i>v/c</i> STATIC PRESSURE (P _s)inHg	STACK TEMP. (T _S)*F	VELOCITY HEAD (Δ P _s)	ORIFICE PRESSURE DIFFER- ENTIAL (Δ H) In. H ₂ O	GAS SAMPLE VOLUME (Vm)ft. ³	GAS SAMPLE TEMPERATURE AT DRY GAS METER		SAMPLE BOX TEMPERA- TURE °F	TEMPERA- TURE OF GAS LEAVING LAST EXPANDER °F
							INLET (Tm _{in} °F)	OUTLET (Tm _{out} °F)		
-	135	10	320		.20	303.47	112	128	250	68
-	145	11	320		.20	306.07	112	129	250	68
-	155	12	320		.20	308.70	112	130	250	68
→	159' 11"	12.5	320		.20	309.89	112	130	250	68
	(159' 11")									
TOTAL	159' 11"						Ave. 102	Ave. 118		
AVERAGE					0.20	10.83	Ave. 110		250	

307-10

RUN # IESTB-111280

O ₂	10.08% O ₂
CO ₂	12.2%
CO	175 PPM
NO	70 PPM
NO _x	72 PPM
HC	2.0 PPM
STACK TEMP	384°F
SMOKE	7.58 (Avg)
ΔT HEAT EXCHANGER	28°F
HEAT EXCHANGER FLOW	1.5 GPM
BURNER FEED RATE	0.260 RPM X 140 gms/R = 4.82 lbs/hr.

TEST B - 111280

$$n_{std} = .3858 \times 1.162 \times 1 \left(\frac{768.35 + \frac{5.08}{13.6}}{302.105} \right)$$

.4483

$$\left(\frac{768.72}{302.105} \right) =$$

$$110.28 \text{ ft}^3$$

$$1.140 \text{ m}^3$$

$$n_{std} = .001333 \times 77 = 102.64 \text{ m}^3$$

$$n_s = \frac{1.140}{1.140 + 102.64} = 9.17\%$$

APPENDIX D

NC STATE UNIVERSITY'S
FUEL COMPOSITION TESTING RESULTS

North Carolina State University
School of Engineering

Engineering Research Services Division

November 14, 1980

P. O. Box 5095
Raleigh, NC 27650
(919) 737-2345

Mr. Werner Martin
Integrated Energy Systems
301 North Columbia St.
Chapel Hill, NC 27514

Dear Mr. Martin:

I am enclosing the results of the analysis work we did on the wood pellet fuels which you are using in your tunnel burner development studies. For samples of wood pellets (as well as the residue from various stages of the burning process), we determined the moisture content, ash content, volatiles content and fuel value (BTU/lb). It is my understanding that the sample designations denote samples taken at different places along the burner. Further, it is my understanding that sample 1 was ash from the bottom of the boiler combustion chamber, sample 2 was the residue in the tunnel burner from the tip to a depth of 2 inches into the burner, sample 3 was the residue from the depth of between 2 and 4 inches into the burner, sample 4 represents material between 4 and 6 inches into the burner, and subsequent samples represent the material taken from the burner at 2 inch intervals going back toward the flange/auger connection. This would place sample 9 at a depth of 16 to 18 inches into the burner while sample 10 was taken at the flange/auger connection and sample 11 was pellets directly from the feed hopper. It is also my understanding that these samples were taken after the burner had been in operation under stable conditions for a period of 2 hours at a feed rate of 39,600 BTU/hr. (0.082 lb/min.) which would give an average "pellet" residence time of 17 min. These conditions are included to assure completeness and to provide the necessary framework for discussing the results of the analysis.

Table 1 shows the results of the analyses on an as-received basis, Table 2 shows the same results after correcting for moisture content (i.e., on a moisture free basis) and Table 3 shows the results after correcting with both ash and moisture contents (i.e., on a moisture and ash free basis). Analysis of the data presented in these tables shows no real surprises. basically, as one would expect, as moisture and volatiles are evolved fixed carbon and ash content increase, with an attendant increase in the BTU content. This latter occurrence is explained by the higher BTU content of the carbon in relation to the volatiles. It should be noted that the BTU analyses were not conducted on samples 1-7 because of the difficulty of preparing the samples for ignition in the bomb calorimeter. As the volatiles content is decreased, the natural adhesives of the material decrease, making it impossible to prepare pellets from the as-received materials (i.e., partially burned wood).

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Mr. Werner Martin

November 14, 1980

It should be noted that the evolution of both moisture and volatiles was essentially complete before the pellets reached a point where combustion would likely occur which would be at and forward of the point where combustion air is introduced (corresponding to sample 5). It is interesting to note that the moisture content of sample 5 increased significantly over that of sample 6. A possible explanation may be in the fact that by this time the sample is composed principally of carbon and ash which is mostly small silica particles, both of which would have a high affinity for water compared to the pellets. This, coupled with the introduction of moist air, may account, at least in part, for the increase in moisture content of this sample. Another partial explanation may be simply that the sample absorbed moisture from the atmosphere during cooling. The fact that samples 1 through 4, especially samples 1 and 2, showed measureable amounts of moisture would indicate that they had, in fact, absorbed moisture from the atmosphere during or after cooling.

The results obtained from sample 2 are unexplainable. One would expect that this sample would be essentially completely combusted and would be almost completely ash, as in the case in sample 1. Obviously, something happened either in the collection or analysis of the sample which was not detected. I would place little or no value on the results from this sample.

The total results from these analyses would be consistent with theories of burnings for pyrolysis of wood. As the material is heated the moisture and volatiles are evolved which gives rise to an increase in fixed carbon and ash content. The gaseous products from the pyrolysis start to burn which, in turn, provides energy for sustaining the pyrolysis reactions and for increasing the temperature of the resultant material so that combustion or oxidation of this material can occur. The combustion of the carbon, in turn, further increases the flame temperature giving rise to the higher temperature recorded near the end of the tunnel burner.

To determine the effect of the volatiles and fixed carbon on the total BTU content of the wood pellets, a series of experiments were conducted in which the pellets were volatilized and the BTU content of the resultant material was determined. To be able to make these necessary samples from this material for bomb calorimetry, it was necessary to use a binder whose BTU content was known. Once the BTU value of the fixed carbon was determined, the BTU content of the volatiles could be calculated using the ratio of the fixed carbon to volatiles and the known BTU content of the starting wood pellets. The experimentally determined value for the fixed carbon was 14,570 BTU/lb. and the calculated value for the volatiles was 7,346 BTU/lb or approximately 2 times the number of BTU's for the carbon as for the volatiles. The samples used for these determinations were also evaluated for their ash content which was found to average 3.2%. The average volatiles content was 81.15% and the average fixed carbon content was 15.64% (on a moisture-free basis). Using these percentages and the BTU values determined or calculated

Page 3
Mr. Werner Martin
November 14, 1980

for fixed carbon and volatiles, respectively, one can then determine the contribution toward the total BTU content from the various component materials by simply multiplying the BTU values for each component by the fraction of the sample represented by that component. Since the BTU value of the ash would be zero, this would yield a contribution of 2,279 BTU's from the fixed carbon and 5,962 BTU's from the volatiles; for a total of 8,241 BTU's. This would indicate that the volatiles contribute 72.3% of the total heating value while fixed carbon contributes 27.7%.

I am sending under separate cover, a Figure which shows graphically the relationships between moisture, ash, volatiles and fixed carbon. These relationships are plotted on both an individual and a cumulative basis. This is essentially the same Figure which I have previously supplied to you.

I trust this information will be useful to you and if you should have questions or comments, please do not hesitate to contact me. I apologize for the delay in getting this report to you, but these last few months have been filled with the ending of several projects and the beginning of several new ones. I am enclosing, herewith, an invoice for this work.

I trust your upcoming European trip will be both rewarding and enlightening.

Best wishes.

Sincerely yours,

B. M. Gay (cc)

B. M. Gay
Assistant Director

BMG/cc

Enclosures

cc: R. F. Stoops

Table I. Proximate and BTU Analyses of Wood and Wood Ash Materials (as-received)

<u>Sample Designation</u>	<u>Moisture Content</u>	<u>Ash Content</u>	<u>Volatiles Content</u>	<u>Carbon Content</u>	<u>BTU/lb. (gross) Content</u>
1	0.8	94.7	5.7	0.0	--
2	1.8	19.3	6.6	72.3	--
3	1.3	40.1	6.2	52.4	--
4	0.4	39.0	5.6	55.0	--
5	2.9	38.0	8.9	50.2	--
6	1.7	17.6	14.4	66.3	--
7	3.0	15.9	23.2	57.9	--
8	3.6	3.4	75.5	17.5	8,288
9	5.8	3.6	77.1	13.5	7,898
10	9.1	3.4	73.5	14.0	7,775
11	10.4	3.8	73.1	12.7	7,553

Table II. Proximate and BTU Analyses of Wood and Wood Ash Materials Corrected for Moisture (Moisture free basis)

<u>Sample Designation</u>	<u>Ash Content</u>	<u>Volatiles Content</u>	<u>Carbon Content</u>	<u>BTU/lb. (gross) Content</u>
1	95.5*	5.7*	--	--
2	19.7	6.7	73.6	--
3	40.6	6.3	53.1	--
4	39.2	5.6	55.2	--
5	39.1	9.2	51.7	--
6	17.9	14.6	67.5	--
7	16.4	23.9	59.7	--
8	3.5	78.3	18.2	8,598
9	3.8	81.9	14.3	8,384
10	3.7	80.9	15.4	8,553
11	4.2	81.6	14.2	8,430

Table III. Proximate and BTU Analyses of
Wood and Wood Ash Materials
Corrected for Moisture and Ash
(moisture and ash free basis)

<u>Sample Designation</u>	<u>Volatiles Content</u>	<u>Carbon Content</u>	<u>BTU/lb. (gross) Content</u>
1	126.7*	--	--
2	8.3	91.7	--
3	10.6	89.4	--
4	9.2	90.2	--
5	15.1	84.9	--
6	17.8	82.2	--
7	28.6	71.4	--
8	81.1	18.9	8,910
9	85.1	14.9	8,715
10	84.0	16.0	8,882
11	85.2	14.8	8,800

*The volatiles content is incorrect due to variations in samples analyzed. Obviously, the volatiles content would be very low in this sample and if anything remained, it would be carbon.

NC-79-004

HEAT HARVESTER CORPORATION

307 N. Columbia Street
Chapel Hill, NC 27514
(919) 942-2007

HEAT HARVESTER TUNNEL BURNER

The Tunnel Burner is an advanced combustion chamber design, especially suitable for attaching to existing oil fired boilers and furnaces. The burner is adjustable to burn green or dry wood chips, wood pellets, and a variety of crop waste such as peanut shells and almond hulls. Combined with an automatic fuel feed system, the burner has been incorporated into an automatic system at Hope Valley School, Durham County Schools, Durham.

The burner has several advanced features which allow high efficiency, low air pollution emissions and convenience:

1. Preheating of combustion air
2. High turbulence through forced combustion air jets
3. Pre-drying and gasification phase incorporated in combustion chamber design
4. Ash retrieval at discharge end of burner
5. Electric starter coil

Development of the original idea was partially sponsored by DOE's Appropriate Technology Program. Less than three years of development work were needed to get the burner optimized for pellets and chips. Plans have already been made to commercialize the burner. It is expected that several licenses will be issued before the end of 1982.

The Hope Valley School installation represents a typical oil fired boiler set-up. It heats approximately 4,000 sq.ft. of the library wing. The boiler capacity is 350,000 BTU/hr. The controls are set to cycle the

oil burner between 3.5 and 5.0 psi steam pressure. The Tunnel Burner uses the same controls as the oil burner and a three way switch allows a change over from wood to oil in seconds. Oil consumption in 1980/81 was 3,500 gal. The Tunnel Burner, with a capacity of 300,000 BTU/hr, will burn 65-70 tons of green wood chips to replace that oil consumption. With a fuel cost advantage for wood chips of \$4.66* per million BTU, Hope Valley school will save \$2,200 annually. At an approximate installed cost of \$6,000 for the Tunnel Burner conversion, the investment will be recovered in 3 years.

For more information contact Werner Martin or Daniel R. Koenigshofer at Integrated Energy Systems.

* oil at \$1.08/gal, wood chips at \$22/ton

- 1 BOILER
- 2 METERING BIN
- 3 WOOD CHIP STORAGE
- 4 TUNNEL BURNER
- 5 SCREW CONVEYOR
- 6 OIL BURNER

FIGURE 1 Tunnel Burner Installation at Hope Valley School, Durham, NC

Heat Harvester "Tunnel Burner" at Hope Valley School,
Durham, N.C.; Retrofit on 350,000 BTU/hr Oil Fired
Kewanee Steam Boiler, April 1982

Heat Harvester "Tunnel Burner" at Test Stand, 40,000 BTU/hr,
Burning Wood Pellets, October 1981

*newspaper article and
reprint removed -*