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Bottomless Arch Selection for Fish Passage

Some Considerations in Using Wood for Energy

SDEDC's McKenzie Wins Cash Award

Guidelines for Estimating Soil Support Values in Ochoco National Forest

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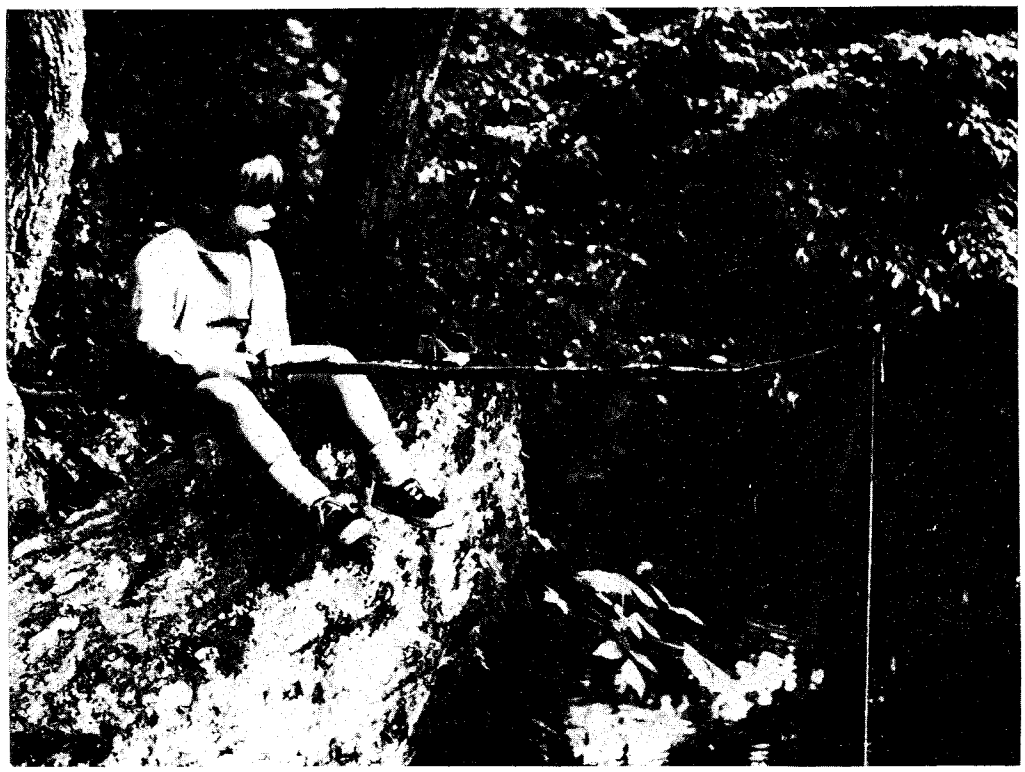
Bottomless Arch Selection for Fish Passage

Roger V. White, Hydraulic Engineer, Region 1

The following program, written in BASIC, is one of several used in Region 1 to aid in culvert selection for stream crossings where fish passage is required. The program assumes open channel flow and uniform flow through a bottomless arch using Manning's equation. Flow depth is limited to the height of the arch to insure open channel hydraulics using a free water surface.

If fish passage is not a prime consideration, circular culvert selection, using a headwater depth greater than the top of the culvert, and inlet versus outlet control analysis, is recommended for better hydraulic efficiency in a closed-conduit flow regime.

The program shown on the following pages was written on an Olivetti P6060 and should be convertible to most BASIC language machines with alterations in the print and dimension statements.



Fish passage has an impact on recreation in the National Forests.

BOTTOMLESS ARCH HYDRAULICS

```
ENTER SPAN IN FEET & INCHES
EXAMPLE:  A 16'4" SPAN...ENTER 16,4

ENTER RISE IN FEET & INCHES
EXAMPLE:  A 8'0" RISE...ENTER 8,0

AN ARCH 16FEET  4INCHES WIDE BY  8FEET  0INCHES HIGH WAS CHOSEN

ENTER RISE TO SPAN RATIO..(either .3,.4,or.5)
                                   .5
ENTER SLOPE OF STREAMBED
                                   .02
ENTER N FOR STREAMBED
                                   .05
ENTER N FOR CULVERT ROUGHNESS
                                   .035
```

FLOW (CFS)	DEPTH (FEET)	VELOCITY (FT/SEC)
15.15	0.40	2.27
47.25	0.80	3.54
90.26	1.20	4.54
142.52	1.60	5.40
201.15	2.00	6.13
266.20	2.40	6.79
335.11	2.80	7.37
408.74	3.20	7.90
482.50	3.60	8.35
559.57	4.00	8.78
632.80	4.40	9.12
708.13	4.80	9.45
775.57	5.20	9.69
844.13	5.60	9.92
900.03	6.00	10.06
956.30	6.40	10.18
991.92	6.80	10.19
1027.52	7.20	10.19
1006.74	7.60	9.80
989.32	8.00	9.46

FILE BOARCH

```
0010 DIM E(20),F(16),G(12),H(20),I(16),J(12)
0020 READ E(1),E(2),E(3),E(4),E(5),E(6),E(7),E(8),E(9),E(10)
0030 READ E(11),E(12),E(13),E(14),E(15),E(16),E(17),E(18),E(19),E(20)
0040 DATA .025,.05,.0745,.099,.123,.147,.1705,.194,.2165,.239
0050 DATA .26,.281,.3,.319,.3355,.352,.365,.378,.385,.392
0060 READ F(1),F(2),F(3),F(4),F(5),F(6),F(7),F(8)
0070 READ F(9),F(10),F(11),F(12),F(13),F(14),F(15),F(16)
0080 DATA .024,.048,.0715,.095,.1175,.14,.161,.182
0090 DATA .201,.22,.2365,.253,.266,.279,.286,.293
0100 READ G(1),G(2),G(3),G(4),G(5),G(6),G(7),G(8),G(9),G(10),G(11),G(12)
```

```
0110 DATA .0225,.045,.066,.087,.106,.125,.1415,.158,.171,.184,.191,.198
0120 READ H(1),H(2),H(3),H(4),H(5),H(6),H(7),H(8),H(9),H(10)
0130 READ H(11),H(12),H(13),H(14),H(15),H(16),H(17),H(18),H(19),H(20)
0140 DATA .05,.1,.1505,.201,.253,.305,.3585,.412,.468,.524
0150 DATA .584,.644,.7095,.775,.851,.927,1.0235,1.12,1.345,1.57
0160 READ I(1),I(2),I(3),I(4),I(5),I(6),I(7),I(8)
0170 READ I(9),I(10),I(11),I(12),I(13),I(14),I(15),I(16)
0180 DATA .052,.104,.1575,.211,.267,.323,.383,.443
0190 DATA .5085,.574,.65,.726,.8225,.919,1.144,1.369
0200 READ J(1),J(2),J(3),J(4),J(5),J(6),J(7),J(8),J(9),J(10),J(11),J(12)
0210 DATA .056,.112,.172,.232,.2975,.363,.439,.515,.708,.933,1.158
0220 RESTORE
0230 PRINT "                        BOTTOMLESS ARCH HYDRAULICS"
0240 PRINT
0250 PRINT "ENTER SPAN IN FEET & INCHES"
0260 PRINT "EXAMPLE:  A 16'4" SPAN...ENTER 16,4"
0270 PRINT
0280 INPUT D1,D2
0290 LET D3=D2/12
0300 LET D=D1+D3
0310 PRINT "ENTER RISE IN FEET & INCHES"
0320 PRINT "EXAMPLE:  A 8'0" RISE...ENTER 8,0"
0330 PRINT
0340 INPUT K1,K2
0350 LET K3=K2/12
0360 LET K=K1+K3
0370 :AN ARCH###FEET###INCHES WIDE BY ###FEET###INCHES HIGH WAS CHOSEN
0380 PRINT USING 370,D1,D2,K1,K2
0390 PRINT
0400 PRINT "ENTER RISE TO SPAN RATIO..(either .3,.4,or.5)"
0410 INPUT C
0420 PRINT ,,C
0490 PRINT "ENTER SLOPE OF STREAMBED"
0500 INPUT S
0510 PRINT ,,S
0520 PRINT "ENTER N FOR STREAMBED"
0530 INPUT N1
0540 PRINT ,,N1
0550 PRINT "ENTER N FOR CULVERT ROUGHNESS"
0560 INPUT N2
0570 PRINT ,,N2
0580 PRINT
0590 PRINT "                FLOW (CFS)    DEPTH (FEET)   VELOCITY (FT/SEC)"
0600 LET B=1.486*S↑.5
0610 IF C<>.5 THEN 780
0620 LET X=1
0630 LET L=.05*K
0640 LET D=1*D
0650 LET A=E(X)*D*D
0660 LET P=H(X)*D+D
0670 LET P1=H(X)*D
0680 LET R=A/P
0690 LET N=(N1*D+N2*P1)/P
0700 LET Q=B*A*R↑.667/N
0710 LET V=Q/A
0720 :            ########.##          ####.##          ####.##
```

```
0730 PRINT USING 720,Q,L,V
0740 LET X=X+1
0750 LET L=L+.05*K
0760 IF X=21 THEN 1140
0770 GOTO 650
0780 IF C<>.4 THEN 940
0790 LET X=1
0800 LET L=.0625*K
0810 LET D=.98*D
0820 LET A=F(X)*D*D
0830 LET P=I(X)*D+D
0840 LET P1=I(X)*D
0850 LET R=A/P
0860 LET N=(N1*D+N2*P1)/P
0870 LET Q=B*A*R↑.667/N
0880 LET V=Q/A
0890 PRINT USING 720,Q,L,V
0900 LET X=X+1
0910 LET L=L+.0625*K
0920 IF X=17 THEN 1140
0930 GOTO 820
0940 IF C<>.3 THEN 1100
0950 LET X=1
0960 LET L=.083333*K
0970 LET D=.917*D
0980 LET A=G(X)*D*D
0990 LET P=J(X)*D+D
1000 LET P1=J(X)*D
1010 LET R=A/P
1020 LET N=(N1*D+N2*P1)/P
1030 LET Q=B*A*R↑.667/N
1040 LET V=Q/A
1050 PRINT USING 720,Q,L,V
1060 LET X=X+1
1070 LET L=L+.083333*K
1080 IF X=13 THEN 1140
1090 GOTO 980
1100 PRINT "YOU MUST ENTER .3,.4,or .5 FOR THE RISE TO SPAN RATIO"
1110 INPUT C
1120 PRINT ,,C
1130 GOTO 610
1140 PRINT
1150 PRINT "ANOTHER RUN...HIT THAT 1..."
1160 INPUT B1
1170 IF B1=1 THEN 10
1180 END
```

END OF LISTING

Some Considerations in Using Wood for Energy

George Lippert, Chief Facilities Engineer, Washington Office

Presented at the Washington Section Meeting of the Society of American Foresters, Annual Science Day, May 26, 1982.

You are aware of the increased demand for and the use of wood for energy. Several considerations should be of interest to those who wish to promote the responsible use of wood as an important source of energy. This paper will cover

1. Problems associated with using wood for energy;

2. The physics and thermochemistry of wood combustion;

3. Cost considerations of systems, components, and the fuel; and

4. Avenues for improving the use of wood for energy.

My particular interest in wood energy arises from the need to increase the use of wood as an energy source in Forest Service facilities.

In keeping with the Forest Service's basic mission to promote the responsible use of wood, and to maintain and operate the Agency's physical plant life cycle in a cost-effective manner, some interesting issues have developed with respect to the use of wood as an energy source.

Except for the casual installation of several hundred small wood stoves, very few wood energy systems have been designed for and installed in Forest Service buildings. We are seeking to improve this situation.

Considerable investigative work has been conducted concerning wood energy systems and the design of those systems. Among these efforts were the following:

1. An in-depth feasibility study* was completed in February 1982, covering six selected Forest

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*FS Contract #53-9158-6495; Ekono, Inc., Bellevue, Wash., June 1981.

Service buildings for retrofitting to wood energy. The heating demand range of the buildings investigated was from 0.25 million BTUH to 3.0 million BTUH. Clean burning was required to eliminate pollution and maintenance problems.

2. A wood energy systems training session was conducted in March 1982 for our field personnel to learn about characteristics of wood energy system design and to provide an opportunity for preliminary evaluation of possible installations for wood energy systems.

3. Literature searches were made, and discussions were held with several recognized individuals, in particular, Dr. David Tillman, Dr. John Cooper, and Dr. Richard Boubell, who are involved in wood and other related energy fields. Much of the material presented herein was developed through their efforts and the feasibility study mentioned previously.

While some aspects of wood energy include problems that may sound somewhat negative, the promotion of the responsible use of wood for energy requires analysis and development of solutions to these problems.

PROBLEMS

Pollution

Most of you are familiar with the increasing concern regarding wood smoke. Several articles during the past 2 years have described the effect of increased use of wood for residential heating. Some cities--Portland, Oreg.; Medford, Oreg.; Missoula, Mont.; Vail, Colo.; and others--have cited residential wood use as the cause of the increased air pollutant level in those areas. Many cities have imposed or are considering sanctions against wood-burning appliances.

Most people are not aware of several studies that have focused closely on the health aspects of wood smoke as a pollutant. These studies provide some important information. The recently completed Montana air pollution study compared third- and fourth-grade children in Missoula with children in Great Falls. Missoula is noted for thermal inversions and considerable wood smoke pollution, while Great Falls is a well-ventilated city with a relatively low percentage of wood stoves. This study concluded that the children in Missoula have a decrease in lung function averaging 2 percent.

Other studies during the past 4 years that used improved sampling and analysis methods resulted

in very disturbing data. The Monsanto Corporation, in a study for the Environmental Protection Agency (EPA), found that wood smoke contained 25 cancer-causing agents. Dr. John Cooper of the Oregon Graduate Center identified more than 14 cancer-causing compounds and other toxic gases in wood smoke. Cooper speculates that thousands of other toxic chemicals and compounds could be contained in wood smoke, and he states that it is reasonable to assume that many of the 2,000 carcinogenic chemicals found in cigarette smoke will eventually be identified in wood smoke.

Studies conducted at Virginia Polytechnic Institute (VPI) indicate that wood emissions are a significant percentage of the total national emissions from all sources (figure 1). Researchers at VPI calculated that wood may be responsible for roughly 1 percent of NO_x, 2 percent of volatile organics, 2.7 percent of CO, and 50 percent of the Polycyclic Organic Matter (POM) in the total air pollutants in the United States. Of greatest concern are the POM's because of the carcinogenic aspects of many of these compounds.

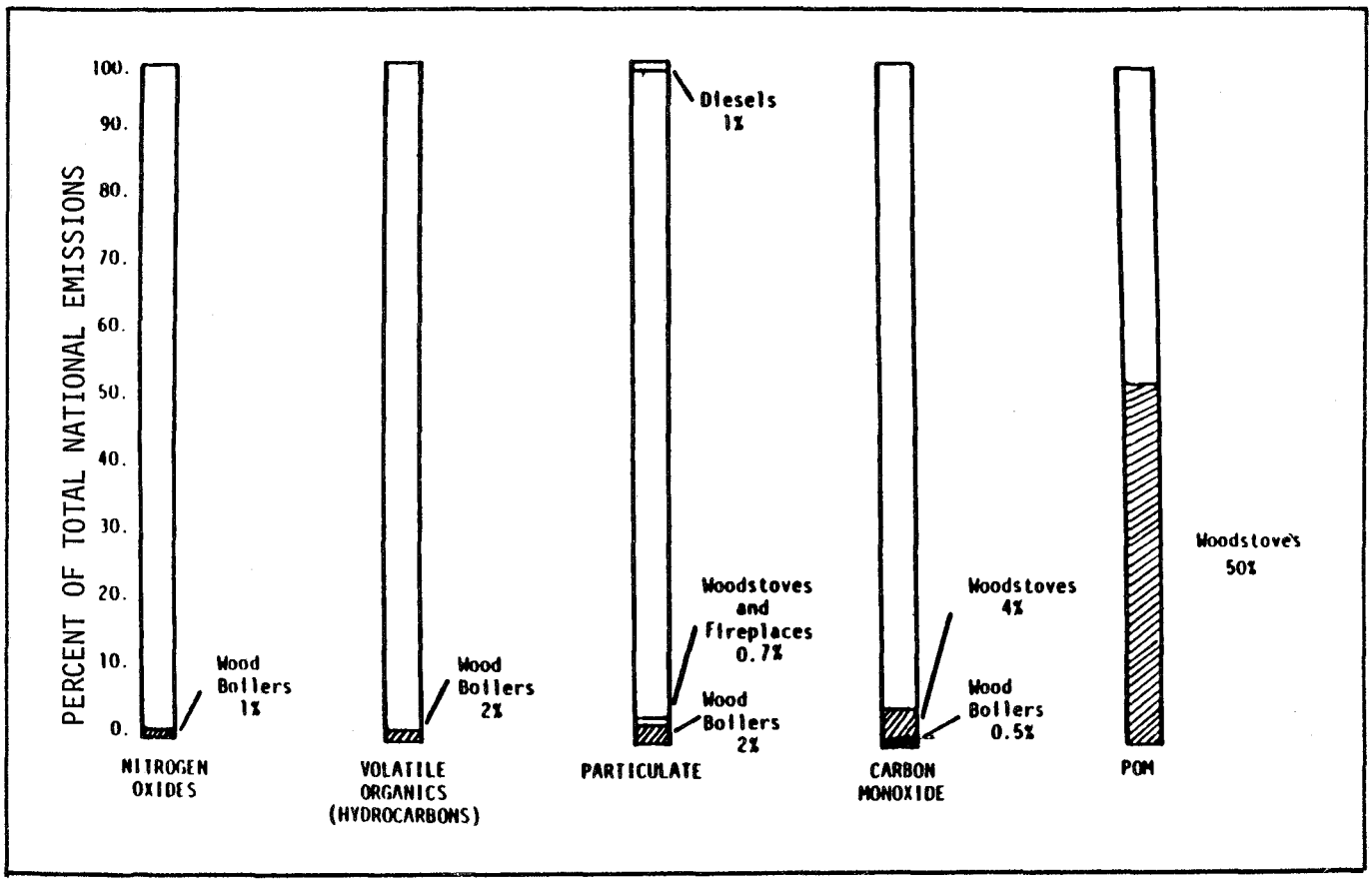


Figure 1.--Relation of wood combustion emissions to the national air pollution emission inventory.

All wood combustion emissions are a serious matter when considered on a localized basis. The VPI study states that, in future years, the tremendous contribution nationally of POM emissions from wood burning may be a major contributor to environmentally caused lung cancer.

Wood smoke pollution is different from the pollution that originates from coal or wood pulp plants, because wood smoke contains solid, rather than gaseous, pollutants. These solids or particulate matter are very small--about 5 microns--and are more harmful than other and larger forms of dust because they can bypass the natural filtering system of the nose and travel deep into the lungs. Wood smoke particulates act as "carriers" for the other compounds and toxic gases.

Correlated data are now being developed. In New Guinea, studies of natives who are constantly exposed to high levels of smoke in their small huts indicate that the majority develop obstructive lung diseases by the time they are 40 years old. Chimney sweeps in England have a high incidence of skin cancer from soot, which has been found to contain benzopyrene. Cooper, Boubell, and others have investigated benzopyrene concentrations by source estimates; table 1 gives some comparisons--note that the last two sources are controlled wood combustion processes. Proper combustion can greatly reduce emissions, and some methods of control are mentioned later. Other sources of emissions are listed in table 2. Table 3 illustrates the effect of excess air during combustion on the level of POM emissions, and table 4 compares emissions from wood burning with combustion of other heating and transportation fuels.

Operation of Equipment

Other problems are associated with the operation of wood energy systems. First, solid fuels present big problems in their use: in material handling, fuel storage, fuel charges, and the variability of the combustion process within the fuel. Second, the basic design of many wood-burning appliances (stoves, boilers, and furnaces) makes it difficult, if not impossible, to maintain uniform performance. Third, and perhaps most critical, is the human factor (particularly for small systems). Fourth, a related wood energy problem is that most practicing engineers have a limited understanding of wood combustion theory.

Source Effluent	Concentration $\mu g/m^3$
Coke oven loading point[a]	33,000
Garbage incinerator[a]	1,400
Auto parts incinerator	170
Wood-fired furnace, 33% excess air	30.06
Vegetable matter incinerator	14
Automobile exhaust[a]	8.5
Hardwood smoke	6.0
Outdoor burning--grass, leaves	4.2
Power plant stack	0.32
Motel space heater (gas)	0.07
Wood-fired furnace, 50% excess air	0.05
Wood-fired furnace, 90% excess air	0.06

[a]Highest value found from range of values.

Table 1.--Benzo(a)pyrene concentrations in selected air pollution source estimates.

Source of Effluent	Concentration of Benzo(a)pyrene	
	ng/g fuel	10^{-6} lb/10^6 BTU
Wood-burning stove	2,500	300
Fireplace	730	100
Forest slash burn, headfire	37-97	5-13
Forest slash burn, backfire	238-3,454	33-473
Forest slash burn, smoulder	55-140	8-19
Grass straw field burn, headfire[a]	374-3,045	51-417
Grass straw field burn, backfire	404-1,839	55-252
Grass straw field burn, smoulder	1-16	0-2
Wood-fired furnace, 33% excess air	274	30
Wood-fired furnace, 50% excess air	0.5	0.06
Wood-fired furnace, 90% excess air	0.6	0.07

[a]Usual burning method.

Table 2.--Benzo(a)pyrene concentrations from selected biomass fuels.

Table 3.--Polynuclear organic emissions as a function of percentage excess air.

Percentage Excess Air	POM Concentrations in $\mu g/m^3$					Total Methylene Chloride Extractables mg/m^3
	Benzo(k)-Fluoranthene	Benzo(e)-pyrene	Fluoranthene	Chrysene	Benzo(a)-pyrene	
33	21.483	11.08	242	27.330	30.06	24.0
50	0.073	0.33	42	0.289	0.05	5.0
90	0.007	0	0	0.012	0.06	3.4

Table 4.--Comparison of emissions from selected residential space heating, power generation, and transportation sources.

Source of Emission	CO $lb/10^6$	NO_x (as NO_2) $lb/10^6$	SO_x (as SO_2) $lb/10^6$	B(a)P $\mu g/10^6$	Particulates $lb/10^6$
Residential space heating					
Gas	0.02	0.08	0.0006	80	0.02
Oil	0.04	0.09	0.3-7	900	0.07
Coal	3.5	0.1	0.5-7	2,500,000	0.6
Wood: fireplace	3.0	0.25		45,000	1.3
Wood: stove	22	0.07	0.03	135,000	1.2
Power generation					
Coal				(20-400)	
Transportation (lb/50 mi)	lb/50 mi	lb/50 mi	lb/50 mi	μg/50 mi	lb/50 mi
Highway vehicles	2.4	0.34	0.02	50	0.06

Source: Cooper, John A., "Environmental Impact of Wood Combustion Emissions and Its Implications," Journal of the Air Pollution Control Association, 30(8), 1980.

Design engineers usually opt for appliances with efficient heat transfer; very few consider the efficiency of the combustion process--the source of the heat. Hence, most appliances are improperly sized for the duty required of them and/or the operating pattern imposed.

Most residential wood stoves are not designed to allow complete combustion of the fuel. The volume of fuel in the combustor and the gas pathways within the combustion chamber do not allow sufficient resident time for completion of the combustion process. Air-tight stoves impede combustion temperatures and starve the fire of the oxygen required for the process.

It is probable that 95 percent or more of all wood-burning appliances are being operated improperly because people lack an understanding of the combustion process or the operating principles associated with that process. Traditional use patterns and sheer laziness also aggravate the situation. Notwithstanding inadequate appliance design (and ignoring the fact that the highest demand for heating usually occurs at night when the indoor/outdoor temperature differences are the greatest), consider for a moment that most operators will load the fire box with the maximum charge that it can physically handle, and then will bank or choke off the air supply. And so, to sleep . . . while the combustion temperature drops, limiting the combustion process, and the large fuel volume in the combustion chamber prevents completion of gas phase combustion. The results are very high particulate emissions and large volumes of ash and char, but a well-rested operator.

Two weeks ago, I received a call regarding the resolution of an operating problem. A 300,000 BTUH wood-fired warm-air furnace was installed last fall during construction of a new Ranger Office in central Idaho. During the winter operation of the furnace, there was considerable smoke, ash, and char; in addition, the heat output fluctuated wildly and caused the electric auxiliary duct heaters to malfunction. The electric duct heaters are designed to have limited temperature and consistent air flow across the coils.

After experimentation, the operating personnel found that they were able to provide a uniform level of heat with limited emissions and char; this improvement resulted principally from reducing the fuel charge from the original "4-hour

load" to a size that would burn efficiently and completely in 1-1/2 hours.

Wood combustion is a complex subject and only recently has been introduced as coursework in selected universities. Unlike the combustion process for other fuels, that of wood has several unique chemical and physical characteristics, and these must be considered.

Some designers and engineers specialize in wood energy systems, but generally, the mechanical engineers working in the HVAC field know little about wood energy. As a result, they usually do not consider wood in fuel selection studies; further, their experiences with wood vary greatly.

This limited knowledge base has a regressive effect on the availability, design, selection, and operation of wood energy systems. Lack of both demand and opportunity further retards improvements needed in the design and operation of these systems.

PHYSICS and THERMOCHEMISTRY

To be able to provide efficient and clean wood combustion, and thus support the responsible use of wood for energy, the physics and thermochemistry of the wood combustion process must be understood. Wood combustion is a chemical process by which the carbon and hydrogen in fuel react with oxygen to form carbon dioxide and water. In the conversion of carbon to carbon dioxide, and in the conversion of hydrogen to water, useful heat is released. The pathways to these combustion products involve free radical chemistry and free radical reactions; these reactions depend on the three "classical T's": time, temperature, and turbulence.

An understanding of the thermochemistry of wood combustion allows comprehension of the behavior of a fuel in the combustion chamber, thereby permitting careful analysis and subsequent improvement in the operation of the boiler. One way to illustrate the uniqueness of these combustion characteristics is to compare those of wood and a familiar solid fuel--coal.

Table 5 shows that the ratio of volatile matter to fixed carbon varies considerably in wood and coal. In wood, the ratio of volatile matter to fixed carbon is approximately 3:1; compare that to coal, which is less than 1:1. A typical chemical analysis of wood is shown in table 6; there are few differences in the chemical composition of wood by species.

Table 5.--Proximate analyses of wood and coal.

Fuels	MC (%)	Volatile matter (%)	Fixed carbon (%)	Ash (%)
Bituminous coal	2.5	37.60	52.90	7.00
Hardwood (wet)	45.6	48.58	5.52	0.30
Hardwood (dry)	--	89.31	10.14	0.56
Southern pine (wet)	52.3	31.50	15.90	0.29
Southern pine (dry)	--	66.00	33.40	0.60

Table 6.--Typical analyses of wood, dry.

Type of wood	Percentage by Weight					
	Carbon	Hydrogen	Sulfur	Oxygen	Nitrogen	Ash
Softwoods						
Cedar, white	48.80	6.37	--	44.46	--	0.37
Cypress	54.98	6.54	--	38.08	--	0.40
Fir, Douglas	52.30	6.30	--	40.50	0.10	0.80
Hemlock, western	50.40	5.80	0.1	41.40	0.10	2.20
Pine, pitch	59.00	7.19	--	32.68	--	1.13
white	52.55	6.08	--	41.25	--	0.12
yellow	52.60	7.02	--	40.07	--	1.31
Redwood	53.50	5.90	--	40.30	0.10	0.20
Hardwoods						
Ash, white	49.73	6.93	--	43.04	--	0.30
Beech	51.64	6.26	--	41.45	--	0.65
Birch, white	49.77	6.49	--	43.45	--	0.29
Elm	50.35	6.57	--	42.34	--	0.74
Hickory	49.67	6.49	--	43.11	--	0.73
Maple	50.64	6.02	--	41.74	0.25	1.35
Oak, black	48.78	6.09	--	44.98	--	0.15
red	49.49	6.62	--	43.74	--	0.15
white	50.44	6.59	--	42.73	--	0.24
Poplar	51.64	6.26	--	41.45	--	0.65

Table 7.--Combustion reactions of common fuel elements.

Combustion Reactions	Stoichiometric oxygen and air requirements, lb/lb fuel	
	Oxygen	Air
$C + 1/2\ O_2 = CO$	1.33	5.75
$C + CO_2 = CO_2$	2.66	11.51
$H_2 + 1/2\ O_2 = H_2O$	7.94	34.28
$S + O_2 = SO_2$	1.00	4.31

Table 7 shows the generalized combustion reaction of the fuel elements. "Stoichiometric air" is the theoretical quantity of air that is required for complete combustion. The term "excess air" is the additional air over the amount of stoichiometric air that is required for combustion based on particle size and rate of reaction.

Physical properties critical to the performance of wood fuel include moisture content, specific gravity, void volume, and thermoproperties (such as specific heat and thermoconductivity). Methods to determine the chemical characteristics that influence the pathways of wood combustion include summative analysis, proximate analysis, and ultimate analysis.

By knowing the specific gravity of wood, we can calculate the void volume of wood. We know that wood is less dense than, say, coal. The void volume indicates the quantity of air within the fuel, and hence its insulative properties and the degree of difficulty encountered in raising the fuel to ignition.

The fractional void volume is an indicator of another major property--moisture content. Moisture content influences specific heat, thermal conductivity, and the overall efficiency of combustion. Thermal properties of wood are largely determined by its specific gravity and moisture content.

Moisture content increases the amount of heat required to raise a particle to combustion temperatures. Moisture content also increases the thermal conductivity of wood. Up to 40 percent, moisture content of wood is often beneficial, as heat can be driven to the center of a wet fuel particle, allowing the particle to dry quickly; this, in turn, permits ignition temperatures to rise quickly within the particle.

Chemical Properties

Summative analysis, i.e., the percentage of cellulose, hemicelluloses, and lignin in the wood, is indicative of carbon-bonding structures and the degree of relative reactivity of elements when they are fractionalized and driven through the combustion pathway. Hydroxyl groups and ether linkage are common in wood.

The summative analysis shows wood to be highly oxygenated, open, and accessible to attack, and a very reactive fuel. The proximate analysis of wood illustrates that the volative to fixed carbon ratio is approximately 3:1.

A conceptual model of the combustion process will serve as a basis for discussion of the reactivity associated with these properties.

It is very important that the hydroxyl radicals and ether chains formed in these zones must go to completion for the combustion to be complete and for the effluent to be relatively clean. The development of radicals and chains can be easily upset by several conditions.

Time, temperature, and turbulence must be sufficient to drive the volatile combustion process to completion. This will be explained later.

It is important also to remember that both endothermic and exothermic reactions are occurring in the combustion process; and in real situations, due to the type of fuel, fuel level, and specific conditions within the fuel, all five steps described above are occurring simultaneously within the fuel pile.

While complete combustion should prevent an effluent with pollutants, stack temperature must be sufficient (usually above 350°F) to insure that any unburned particulate released during the burning cycle does not condense in the stack. These creosote deposits can readily develop with a cool, slow-burning fire.

Figure 2 is a fire "zone" or "step" conceptual model of solid fuel combustion. In the first step, the solid fuel is heated and dried. Two things occur in the second or pyrolysis zone. In this zone, operating at 570°F to 1,800°F, carbon and volatiles are separated. The volatiles and steam are driven to three additional

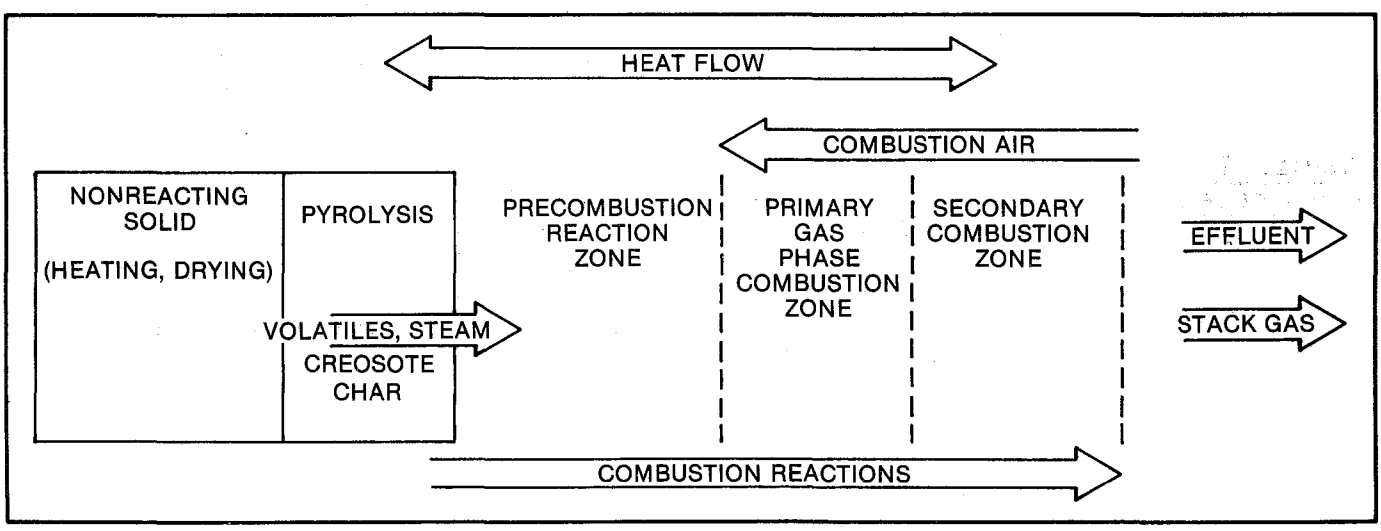


Figure 2.--Conceptual model of solid fuel consumption.

gas phase combustion zones, leaving the carbon (char) to combust in this zone. Char oxidation leads directly to carbon dioxide (CO_2) and carbon monoxide (CO). The CO then reacts further in the gas combustion zones. Two considerations should be kept in mind. Char formation is inversely proportional to combustion temperatures. Also, the higher the moisture content, the higher the percentage of char. Overemphasis on char production without sufficient resident time in the gas phases of the combustion will cause CO emissions.

The next three zones are the critical gas phase combustion zones. In the precombustion reaction and primary gas combustion zones, free radical reactions occur rapidly. In the former zone, hydrogen-carbon-oxygen (H-C-O) chains are initiated from pyrolysis of cellulose, hemicellulose, and lignin. H-C-O chain propagation occurs in the primary zone. H-C-O chain termination occurs in the secondary combustion zone.

Proper design of a combustor takes these combustion zones into account; some may overlap. Wood stoves generally have a very limited combustor volume. Because of the large volume of volatiles that react to heat, and the large number of gas compounds given off, the combustor must be of sufficient volume to allow these products to form and then to combust. Because these compounds are traveling in the form of a turbulent gas, the combustor must be of sufficient size to allow the resident time that is required for proper combustion to take place. Insufficient resident time attributes to the high level of pollutants that are emitted as a result of poor combustion.

Of course, the moisture content of wood will be an important factor in the production of steam, which can occupy a considerable volume of the combustor. Proper appliance selection and operation must consider all factors occurring with the five zones and the characteristics of the fuel used.

How Do the "Three T's" Come into Play?

If temperatures are low, pyrolysis probably will produce more char and more long-chain volatiles; interruption of the combustion process and incomplete combustion are more likely to occur, resulting in a loss of combustion efficiency and an increase in emission of pollutants.

If sufficient time is provided, then the combustion of gases is quenched; again, incomplete

combustion with increased hydrocarbon emissions results.

Turbulence is provided by the vigorous mixing of gases and oxidants in the gas phase zone. Again, if inadequate mixing takes place, incomplete combustion is probable.

As I mentioned earlier, most engineers have been concerned with the efficiency of heat transfer, which occurs after combustion. To obtain clean wood combustion, we must be equally--if not more--concerned with the efficiency of the combustion process. After all, that process is the source of the energy we use to perform work.

These efficiencies are largely affected by the thermal characteristics of the wood and three conditions:

1. Flame temperature,
2. Moisture content, and
3. Excess air.

Flame temperature determines the efficiency (completeness) of individual reactions. Moisture content influences the rate at which the fuel heats up, the completeness of heating the whole particle, and the entire range of products resulting from wood combustion. Moisture aids in radiant heating in the gas phase zone and in heat transfer between zones. The amount of excess air is critical; an incorrect quantity of excess air can reduce the flame temperature and the resident time needed for proper combustion. The slope of the curve in figure 3 indicates that moisture content has less influence on flame temperature than does excess air.

Pollutant formation is influenced by all the elements that contribute to combustion. The completeness of the combustion process is the principal mechanism for pollutant control.

COST CONSIDERATIONS

There are several ways to discuss the costs of using wood as a primary heat source. One way is to use equivalent costs, expressed in 10^6 BTU of energy delivered. Heating systems vary in the efficiency with which they deliver energy; for example:

1. In the Northern Virginia area, electricity is the most expensive. Electric resistant heaters are 100 percent efficient @ $0.068/KWH = $19.88/MM BTU.

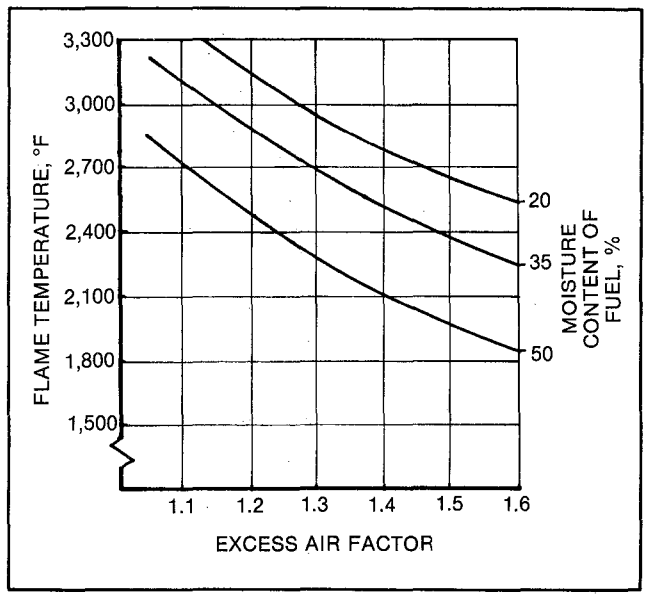


Figure 3.--Influence of moisture content of fuel.

2. Oil furnaces are usually 75 percent efficient, @ $1.15/gal. = $\frac{\$7.83}{.75}$ = $10.44/MM BTU.

3. Natural gas heaters are usually 80 to 85 percent efficient, @ $0.4967/therm = $\frac{.4967}{1.02 \text{ X } .85}$ = $5.676/MM BTU.

4. Wood produces 24,000,000 BTU/cord; @ $100/cord, at 55 percent efficient = $7.58/MM BTU; @ $80/cord, at 30 percent = $11.11/MM BTU.

Another way is to address the comparative costs for a year prior to and after the addition of wood as a heating source. In the residential sector, a University of Idaho study of 800 firewood gatherers revealed that the average estimated annual heating bill savings by using wood were $300. If the average collector burns 5.9 cords per year, the estimated cost (considering transportation, equipment, time, etc.) is $353.41.

In the small-scale commercial sector, a Forest Service study found that there were limited sources of clean-burning appliances available. Of over 200 manufacturers contacted, only 23 had efficient, clean-burning devices--and 8 of these were of foreign manufacture. (See FS Contract #53-9158-6495; Ekono, Inc., Bellevue, Wash., 1981.)

The study concluded that because of the heavy initial investment costs of wood-fired energy systems, as well as cost of available fuels (approximately $2.00/MM BTU for wet chips, bark,

and hog fuels), retrofitting to wood energy would generally not be cost effective if annual energy bills were less than $10,000 a year; it would be satisfactory if energy costs were greater than $15,000 a year. The study used life cycle costing, a 7 percent discount rate, and a 25-year study period.

FUTURE WORK

If we are to increase the use of wood for energy in a responsible manner, there are several areas that require further development: (1) a wider understanding, in both academia and in the engineering consulting field, of the wood combustion process--this process must be considered in system design and operation; (2) controlling the combustion process, as the key to maintaining an acceptable level of pollutant emissions--if controls are not developed, sanctions could be imposed at local or State levels; and (3) improvement in the domestic availability of acceptable, controllable wood energy appliances at reasonable costs.

Wider understanding of life cycle costs, the adverse influence of high initial equipment costs, and the preponderance of evidence of environmental problems that are associated with wood energy will be major deterrents to continued development of wood-fired systems for residential use. Although the statistics on the current growth of residential use of wood energy are impressive, a trend away from the use of wood for residential energy will be noted unless economical, controllable combustion furnaces become available.

Exploration of new market opportunities is also needed; almost all current wood energy use is either in the residential market or in the wood industry. Future markets appear to be the small to medium commercial, industrial, and institutional users in the 0.5 to 10.0 million BTUH range. Alternative Energy Retailer magazine (November 1981) stated that presently ". . . wood and coal are the least used sources of energy in nonresidential buildings across the nation." Considering the number of small- and medium-sized cities in New England, the Great Lake States, and other heavily wooded areas, there are literally thousands of potential new wood energy users. Two factors seem to favor this market:

1. Users in this energy consumption range have the energy demand to offset higher costs of the wood energy system; they can better amortize the investment than can homeowners.

2. Consumers in this range would have less impact on the available wood supply; larger users would require large, specific sources of fuel and have an attendant heavy local impact. The small to medium user, while needing a guaranteed supply, would have less local impact, while providing a use for forest residues from a wider section of sites, and would offer the small-wood-lot owner an outlet for thinnings and so on.

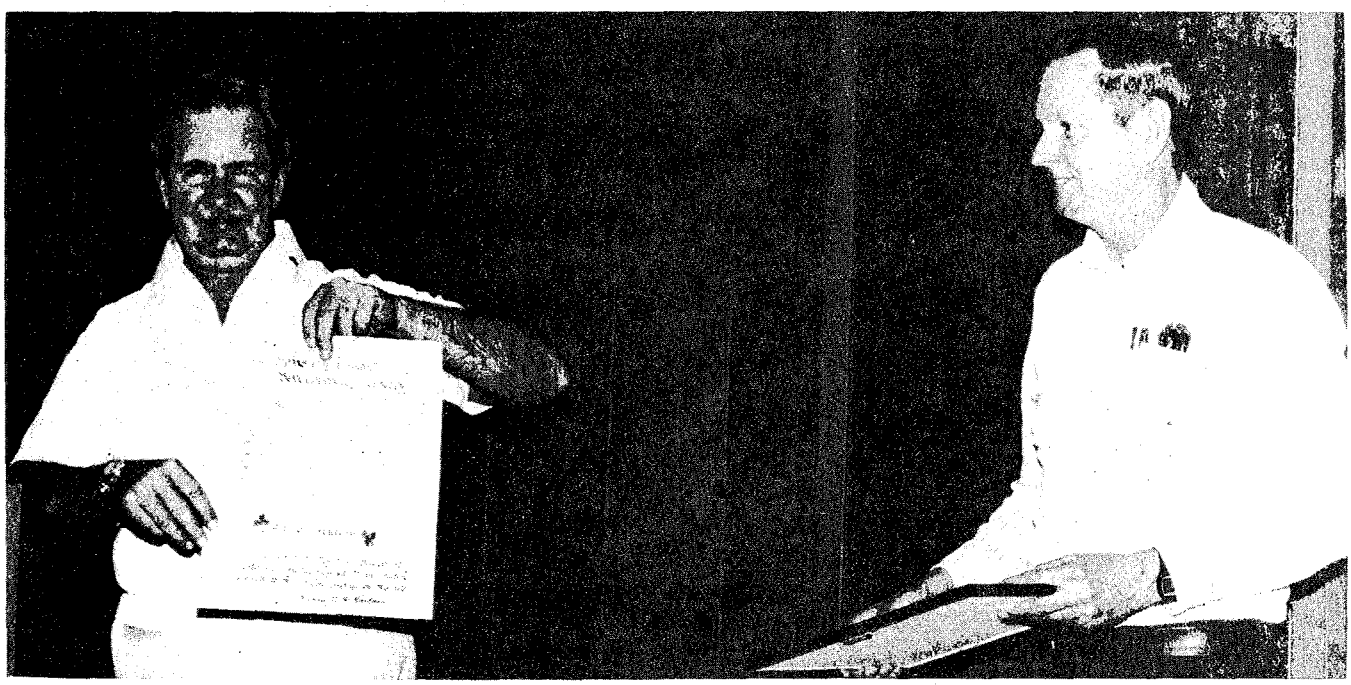
Economics will dictate when opportunities will be exercised, but the future of wood energy will brighten with careful planning and attention to problems associated with its use. While forestry research has addressed the structural, paper making, and other uses of wood, little has been done in the direct and efficient use of wood for energy. Considerable attention has been focused on the wood supply; both supply and use must be addressed in concert to insure the successful use of wood for energy.

Additional insights into the wood energy problem, exploration of opportunities, and new approaches must be included in our consideration.

SDEDC's McKenzie Wins Cash Award

Dan W. McKenzie, Mechanical Engineer with the San Dimas Equipment Development Center, recently was presented with a certificate of merit and a cash award of $1,500 by Boone Y. Richardson, the Center director. McKenzie was recognized for sustained outstanding performance in the area of the transfer and implementation of equipment development technology. His efforts over the past 21 years have led to the latest essential forest management equipment being available to land managers in a timely manner.

At the San Dimas Center, mechanical, civil, and aeronautical engineers; foresters; technicians; and various support personnel conduct an equipment development and test program to provide new and improved specialized equipment to meet national resource goals set by Congress. This effort encompasses projects in timber, range, wildfire prevention and suppression, aviation management, forest engineering, and the treatment and utilization of forest residues. These projects provide both public and private land managers



Dan McKenzie (right), Mechanical Engineer at San Dimas Equipment Development Center, receives award from Boone Y. Richardson (left), SDED Center Director.

with qualified products and up-to-date equipment, materials, techniques, and systems to improve lands and to safeguard them from damage by natural and unnatural forces.

When land managers have identified their needs, Engineers at the San Dimas Center determine suitable approaches to equipment development. Needs are met using state-of-the-art technology to create new concepts through a step-by-step equipment development program. The final step is to see that the new development is implemented in the field to attain the desired results. This is the area in which McKenzie has excelled and for which he was recognized.

McKenzie's dedicated execution of technology transfer has resulted in the availability and implementation over the past two decades of a long list of forest management equipment. His accomplishments include the following:

-- Was instrumental in the development by Timberland Equipment Ltd., Canada, of an intermittent, double-row tree planter (the HODAG) that will help close the reforestation gap on both public and private lands.

-- Provided equipment to improve the vast acreage of forests and rangelands in this country that are under both Federal and private ownership--including such devices as the rangeland drill, the brushland plow, the contour furrower, and the forestland tree planter.

-- Designed seven different models of waterhandling fire engines and tankers that are specifically configured to fight wildfire.

-- Engineered an implement-carrying hitch, a forestland residues machine, electric-motor-driven fire hose reels, and commercial equipment for timber stand improvement and forest residues treatment.

-- Evaluated a hill-climbing backhoe, fire-retardant flow meters, and many other forest engineering, wildland firefighting, and rangeland improvement devices.

In addition to his mechanical engineering duties for the Forest Service, McKenzie is a lieutenant colonel in the Ordnance Corps, U.S. Army Reserve.

Guidelines for Estimating Soil Support Values in Ochoco National Forest

Bruce N. Jorenby, P.E., Geotechnical Engineer, Region 6

This report summarizes engineering soil data collected between August 1978 and November 1980 on Ochoco National Forest and recommends a procedure for estimating soil strength values for use in pavement design. This guide will be useful when time does not permit actual laboratory testing of soils and where it is desired to maximize use of past data on current projects. The primary laboratory test referred to is the California Bearing Ratio (CBR), AASHTO T 193.

The need for such guidelines became apparent when I first came to the Forest and was asked to design pavement structures. The initial approach was to estimate CBR values based on soil classification and the relationships among those developed and published in various references.

One of the main references was Soils Manual (MS-10), published by the Asphalt Institute. Table VI-2, Characteristics Pertinent to Roads and Airfields, of this manual gives typical design values for CBR, based on Unified soil classification. One thing that was discovered when laboratory tests were run on soils previously estimated was that actual CBR values were substantially lower than the values given in the table. Another source of information on soils was the Ochoco National Forest Soil Resource Inventory. This inventory is a compilation of soils data which relates soil properties to various uses (timber, recreation, etc.) and is based on a lower order soil survey. This inventory is useful during the planning stages of engineering projects but falls short in the design phase, where site-specific information is required. For these reasons, it was decided to develop an Engineering Soil Data Base for the Forest. As this data base was developed, greater reliance was placed on it for estimating soil support values, and less on other references. The data base is now at a point where it can be recommended for use as the primary source in selecting soil support values.

ENGINEERING SOIL DATA BASE

The data base consists of a series of tables which contain information on 92 CBR samples (see figure 1) collected on the Ochoco National Forest. The tables list CBR values which correspond to 90 and 95 percent of the maximum density as defined by AASHTO T 99.

These values were selected because they correspond to the compactive effort normally required by the Standard Specifications. The CBR(90) values correspond roughly to the compactive effort required by the "layer placement" method. The CBR(95) values correspond to the 95 percent of AASHTO T 99 method. Although the Standard Specifications allow for greater compactive effort to be required, these densities are generally not achieved. Furthermore, the additional inspection required to verify the attainment of these greater compactive efforts is not available. Consequently, it is recommended that the CBR(95) and CBR(90) be utilized in the pavement design procedure, and the value selected to correspond to the anticipated compaction.

It is important to note that the CBR values listed in most references (such as the Soils Manual) correspond to 100 percent of the maximum density defined by AASHTO T 99. Chapter 50 of the Forest Service Transportation Engineering Handbook gives a procedure to arrive at CBR(95) and CBR(90).

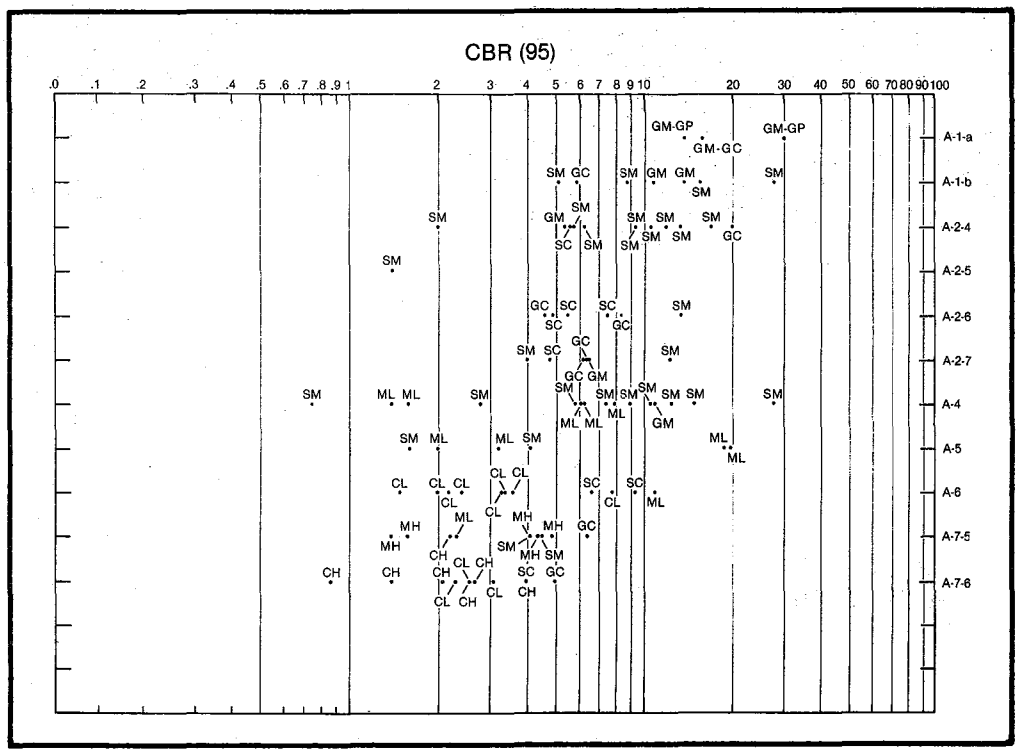


Figure 1.--CBR(95) Unified and AASHTO classification systems.

The Engineering Soil Data Base tables display the following information:

CBR(95) and CBR(90)	
Unified soil classification	
AASHTO soil classification	
Maximum density (100% AASHTO T 99)	Pmax
Optimum moisture	Wopt
Atterberg limits	
Dilatancy (expansion of granular material due to rearrangement of component grains)	DIL
Toughness (field test)	TOU
Dry strength (field test)	S_D
Sample number	
Project number	
Laboratory number	

Two sets of tables are included. One set organizes the data by Unified soil classification, while the other set lists the data by AASHTO soil classification. The two classification systems are included because although the Unified system has many advantages, it does not adequately characterize soil strength as defined by the CBR test. A review of the soil data for a given Unified soil classification shows that a rather broad range of values exists. It is felt that using the two classification systems in conjunction with one another will give a better estimate of CBR value.

The tables list dilatancy, toughness, and dry strength for use in those cases where only hand field classification of soils is available. The tables also list sample, project, and laboratory numbers in order to provide a cross-reference to the road files. This is important because it is often desirable to compare the shapes of CBR and T 99 curves for similar soil types. (See the appendix for an explanation of the Ochoco soil sample numbering system and project numbering system.)

Tables 1 and 2 display the mean, range, and median for each soil type for each soil classification system.

ESTIMATING SOIL STRENGTH VALUES

This description provides a procedure for estimating soil strength values for use in pavement design. Three methods of determining soil strength values are available, and they are generally selected based on time and budget

Table 1.--Unified soil classification table.

SMu Soils Sample	Project	Lab	AASHTO	CBR_{95}	CBR_{90}	Pmax	Wopt.	LL	PL	PI	Dila-tancy	Tough-ness	Dry Strength
2730-22	310-2730-3-5	2003	A-7-5*	4.5	3.1	84.0	26.0	51.9	37.6	14.3	N	M	M
1750-4	310-1730-3-1	3164	A-4*	5.9	2.6	78.3	26.7	33.8	0		Q	N	S
1600-150	320-1600-3-1	3116	A-1-b*	5.1	1.8	95.4	20.5	39.5	0		M	S	--
2730-11	310-2730-3-3	3122	A-2-4*	17.0	8.2	92.4	21.5	36.3	0		Q	N	N
2610-2	320-2610-1-7	3124	A-1-b*	8.8	3.0	113.7	15.2	33.5	0		Q	S	S
42-21	410-41-1-C	3026	A-2-7*	12.5	8.2	85.6	22.6	53.6	41.0	12.6	M	M	H
4230-1	320-4230-1-5	3027	A-4*	15.0	9.0	80.0	26.0	34.0	0		VQ	N	N
41-42	310-41-4-0	3029	A-2-4*	10.8	4.2	94.0	16.4	33.2	29.4	3.4	Q	S	S
45-2	320-45-4-6	3030	A-2-4*	9.5	3.8	98.3	15.1	29.0	0		Q	S	S
4370-650	320-45-4-6	3030	A-4*	7.5	6.0	97.8	21.8	36.0	28.7	7.3	N	M	H
4705-1	320-4705-4-7	3032	A-2-4*	--	5.8	99.6	17.8	38.0	0		M	S	--
41-23.3	310-41-4-0	3070	A-2-6*	13.5		84.2	28.0	36.6	24.5	12.1	S	M	M
41-34	310-41-4-0	3071	A-2-4	12.0	7.7	99.5	18.8	32.0	24.4	7.6	S	S	N
41-38	310-41-4-0	3071	A-5*	4.1	2.9	84.9	23.6	44.7	43.6	1.1	N	H	M
41-38.1C	310-41-4-0	3071	A-2-7*	4.0	2.8	99.9	23.8	41.6 47	38.1 33	3.5 14	N	H	H
41-38.2	310-41-4-0	3071	A-7-5*	4.1	--	88.0	29.8	43.0	31.4	11.6	S	M	M
2600-61	410-2600-1-E		A-2-5	1.4	0.9	75.5	36.0	40.7	31.3	9.4			
27-43	415-27-3*	3167	A-5*	1.6	1.5	90.3	25.3	42.6	33.3	9.3			

Note: N = no reaction; M = moderate; Q = quick; S = slow; H = high dry; VQ = very quick; -- = no run.
* Computed median, not a recorded number.

constraints, as well as on project intensity level. The methods listed below correspond to these intensity levels.

Method 1 involves selecting and classifying representative soil samples and performing the CBR test. The laboratory CBR values are compared to tabulated values for similar soils to determine the reasonability of the results.

Method 2 involves selecting and classifying representative soil samples and determining the maximum density (and optimum moisture) of the soil (T 99). The soil classification and maximum density of the tested soil are compared against tabulated values, and a CBR value (or range of values) is selected for use in design.

Method 3 involves selecting and classifying representative soil samples. Soil classification can be based on hand field tests or on laboratory classification. CBR values are estimated based on these classifications, by comparing them with the tabulated values.

Table 2.--AASHTO soil classification table.

A-6 Sample	Unified	CBR(95)	CBR(90)	Pmax	Wopt	GI
27-41	SC	6.6	2.5	100.0	19.9	3
1750-5	SC	3.6	2.2	92.7	22.8	3
2630-12	SC	9.4	6.7	105.3	19.5	3
41-32	CL	3.6	2.3	102.2	17.6	11
41-61	CL	7.8	4.5	99.4	19.3	5
45-1	CL	2.4	1.3	92.8	21.4	11
41-24.1	CL	3.3	1.5	83.8	23.0	6
41-36.1A	CL	2.0	1.4	99.0	17.5	11
41-38.1B	CL	2.2	1.3	98.9	20.0	11
2630-11	CL	3.4	2.3	99.7	21.5	10
2630-14	CL	1.5	0.65	102.8	19.0	14
2210-1	ML	11.0	5.5	96.1	22.7	4

Generally speaking, estimating CBR values based only on soil classification (method 3) requires considerable experience and is risky. The most desirable method is to run the CBR test for the soils in question (method 1). However, this involves approximately 1 week from the time sampling occurs to the time all test data are in hand, under optimum conditions. As the CBR data base is further expanded, the amount of CBR testing can be reduced.

If time and budget constraints permit only use of method 3, hand field classification of the soils may be adequate. Laboratory testing in this situation is desirable for verifying the field tests and for situations where field testing is not possible.

The method which has the greatest potential benefits for the time invested is method 2. This involves running an additional test--AASHTO T 99. Using the soil classifications, as well as the Atterberg limits, in conjunction with maximum density will aid in selecting a better CBR value. The additional time it takes to run this test, over that of running a laboratory gradation and classification, is probably worth it. This test can be run by a production laboratory or in a field laboratory and can be completed in 1 day. Consequently, it is recommended that this method be used where actual CBR testing cannot be accomplished.

SOILS INVESTIGATION

The initial phase of the investigation consists of segmenting the road based upon visual observations of soil color, landform, and vegetation. An attempt is made at viewing the road project along its entire length. The second phase consists of limited field classification of soils at several locations within each segment. The purpose of this step is to verify the segmentation proposed by the initial work. The data collected are reviewed and, based on a comparison of the work in parts one and two, sample locations are selected. Soil samples are collected at each of the locations selected and labeled according to the Soil Sampling Numbering System. Test pits are dug to determine the soil profile and the depth to rock or solid materials. A large enough sample is taken so that a complete battery of tests may be run, including soil classification and CBR.

Soil classification is run on all samples, and the results are compared with the field classifications. Based on the resulting analysis,

additional sample locations may be selected, and samples may be collected and classified. All soil classification data are reviewed, and samples are selected for CBR testing. The selection is based on how well the individual soil samples are estimated to represent segments of the project.

Following receipt of the CBR test data, a complete review is made of all data and information collected. CBR data are compared with soil classifications and properties to determine if a correlation exists between them. A field review of the project is made to verify the notes taken in part one and the field classifications made. Additional soil samples may be taken as needed. Soil classifications are made on these samples, and additional CBR testing may be done on these samples and on those previously collected. (See tables 3 and 4.)

Table 3.--Summary of soils: Unified.

	Range	CBR(95)		Std. Dev.	Range	CBR(90)		Std. Dev.
		Mean	Median			Mean	Median	
GP	13.7 to 30.0	21.9	--	8.2	6.4 to 30.0	18.2	--	11.8
GMd	10.8 to 30.0	18.2	18.2	8.4	4.0 to 30.0	13.8		11.5
GMu	5.4 to 15.8	10.5	11.0	4.0	3.9 to 9.6	6.3	6.4	2.0
GC	4.6 to 20.0	9.0	(6.45)*	4.9	1.7 to 14.5	5.8	4.5	3.5
SMd	0.75 to 28.0	11.4	9.5	8.3	0.4 to 10.0	3.8	3.5	2.6
SMu	1.4 to 17.0	8.1	7.5	4.6	0.9 to 9.0	4.5	(3.45)*	2.6
SC	3.6 to 9.4	5.8	5.5	1.7	1.4 to 6.7	3.2	2.5	1.8
ML	1.4 to 19.6	7.5	6.2	6.2	0.95 to 12.0	4.1	3.2	3.4
MH	1.4 to 4.9	3.0	(2.85)*	1.5	1.3 to 4.3	2.6	2.2	1.3
CL	1.5 to 7.8	3.1	(2.85)*	1.5	0.65 to 4.5	1.9	(1.55)*	1.0
CH	0.87 to 4.0	2.3	2.2	0.9	0.57 to 1.9	1.4	(1.55)*	0.5

* Numbers in parentheses are computed medians; there were too few numbers to take an "actual" median.

Table 4.--Summary of soils: AASHTO.

	Range	CBR(95)		Std. Dev.	Range	CBR(90)		Std. Dev.
		Mean	Median			Mean	Median	
A-1-a	13.7 to 30.0	19.8	15.8	7.2	6.4 to 40.0	15.3	9.6	10.5
A-1-b	5.1 to 28.0	12.5	10.8	7.2	1.8 to 7.5	4.3	(4.15)*	1.8
A-2-4	2.0 to 20.0	9.8	9.5	4.8	1.6 to 14.5	5.8	4.5	3.3
SMd	2.0 to 13.5	8.1	9.4	3.8	1.6 to 5.8	3.8	10.8	1.5
SMu	5.8 to 17.0	11.0	(4.0)	3.6	3.8 to 8.2	6.0	3.8	1.8
A-2-5		1.4					0.9	
A-2-6	4.6 to 13.5	7.4	6.5	3.1	1.4 to 4.5	2.5	1.7	1.4
A-2-7	4.0 to 12.5	6.7	(6.35)*	2.7	2.8 to 8.2	4.6	(4.25)*	1.8
A-4	0.75 to 28.0	8.4	7.5	6.6	0.40 to 10.0	3.8	3.1	2.9
SMd	0.75 to 28.0	10.6	(9.85)*	8.8	0.40 to 10.0	3.6	3.1	3.2
SMu	5.9 to 15.0	9.5	7.5	4.0	2.6 to 9.0	5.9	6.0	2.6
ML	1.6 to 8.0	4.7	6.2	2.7	0.95 to 5.1	2.3	1.1	1.7
A-5	1.6 to 19.6	8.2	(3.65)*	7.9	1.5 to 12.0	4.8	(2.45)*	4.1
SMu	1.6 to 4.1	2.85	--	1.3	1.5 to 2.9	2.2	--	0.7
ML	2.0 to 19.6	11.0	--	8.4	1.7 to 12.0	6.2	--	4.5
A-6	1.5 to 11.0	4.7	(3.5)	3.0	0.65 to 6.7	2.7	(2.25)*	1.8
SC	3.6 to 9.4	6.5	6.6	2.4	2.2 to 6.7	3.8	2.5	2.1
CL	1.5 to 7.8	3.3	(2.85)*	1.9	0.65 to 5.5	1.9	1.5	1.1
A-7-5	1.4 to 6.5	3.6	4.1	1.6	1.3 to 4.6	2.9	3.1	1.2
SMu	4.1 to 4.5	4.3		0.2				
ML	2.3 to 4.4	3.35		1.0				
MH	1.4 to 4.9	3.0	(2.85)*	1.5	1.3 to 4.3	2.6	2.2	1.3
A-7-6	0.87 to 5.0	2.8	2.6	1.1	0.56 to 3.6	1.7	1.6	0.9
CL	2.3 to 3.1	2.7	2.6	0.3				
CH	0.87 to 4.0	2.3	(2.35)*	1.0	0.57 to 1.9	1.3	1.5	0.5

* Numbers in parentheses are computed medians; there were too few numbers to take an "actual" median.

Once all test data are received, the information is assembled and the project is resegmented. A representative soil support value is selected for each segment to determine the required pavement structure for these segments.

The final phase of soils investigation occurs during the construction phase, after all earthwork is complete but prior to placement of surfacing and base course materials. The project is reviewed to determine the adequacy of the pavement design and to check the design assumptions against the as-built condition. The length of segments may need to be changed at this point, depending upon final placement of soils.

Appendices

PROJECT NUMBERING SYSTEM & SAMPLE NUMBERING SYSTEMS; FILING SYSTEM; & SOIL INVESTIGATION OUTLINE

OCHOCO ENGINEERING PROJECT NUMBERING SYSTEM

The purpose of this project numbering system is to allow for filing and cross-referencing information for various projects over a long-term period. The basic problem it attempts to solve is the organization of information common to a given road or aggregate source, which road or source is used by a number of different projects. The system incorporates the geotechnical work processes in a limited sense in order to indicate the reliability of information.

PROJECT NUMBERING SYSTEM

$$X_1X_2X_3 - Y_1Y_2Y_3Y_4 - Z - T$$

OR

$$X_1X_2X_3 - Y_1Y_2Y_3Y_4 - Z(S)$$

OR

$$X_1Y_2X_3 - Y_1Y_2Y_3 - R(S)$$

X_1 = Work process
- 3: Roads - Design
- 4: Roads - Construction
- 5: Roads - Maintenance
- 6: Aggregate Sources
- 7: Bridges

X_2 = Intensity level
- 1: High
- 2: Medium
- 3: Low

X_3 = Type of Project
- 0: Timber sale
- 5: Capital investment

Y_1Y_2: Arterial road

$Y_1Y_2Y_3Y_4$: Collector road
Local roads are assigned to nearest four-digit road project

$Y_1Y_2Y_3$: Aggregate source number

Z: District number

T: Timber sale number (letter or number, one or two digits)

For capital investment project and maintenance projects

S: Road section number (two digits)

R: Road number (two or four digits)

Examples:

Timber sale road design	320-27-3-4	Road 27 Timber Sale 3-4 Prineville District Stogie Timber Sale Road Design Intensity Level 2
Timber sale road construction	420-27-3-4	Road 27 Timber Sale 3-4 Prineville District Stogie Timber Sale Road Construction Intensity Level 2

Timber sale aggregate source	620-335-3-4	Rail Creek 335 Timber Sale 3-4 Prineville District Stogie Timber Sale Aggregate Source Intensity Level 2
Capital investment project road design	315-42-1(10)	Road 42 District 1 Section 10 Road Design Intensity Level 1
Capital investment project aggregate source	615-133-42(20)	Jungle Creek 133 Road 42 Section 20 Aggregate Source Intensity Level 1
Bridge	710-42-1(20)	Road 42 District 1 Section 20 Bridge Intensity Level 1
Road Maintenance	520-42-1(10)	Road 42 District 1 Section 10 Road Maintenance Intensity Level 2

OCHOCO GEOTECHNICAL ENGINEERING SAMPLE NUMBERING SYSTEM

The purpose of this soil sample numbering system is to organize soil data collected from various projects and allow for retrieval of this information at a later time. This system allows samples to be labeled in the field according to a pre-established sampling system and for this number to serve as a permanent identification.

Each sample is labeled to correspond to the road from which it is taken, as well as to the section of the road. The sample number is independent of the project involved, but is cross-referenced to the project by the Project Numbering System. Samples taken on a given section of road are labeled in a consistent manner, even though they may be from different projects.

Soil data collected are filed in the appropriate road file and maintained for each arterial and collector (two- and four-digit road). These road files serve as the primary and original file for all geotechnical road information. Soil information from a local road is labeled and filed according to the first four digits of its road number.

Arterial Roads

```
41 - 51
|    |└──── Sequential number (1 to 9)
|    └───── Section number (1 to 9)
└──────────  Road number
```

All samples within a given section are labeled sequentially, 41-51 to 41-59. Additional samples in a given section are labeled 41-51.1, 41-51.2, etc. CBR samples taken at a given location, but at different depths within the soil profile, are labeled with letters: 41-51A, 41-51B.

Collector Roads

```
2730 - 31
|      |└──── Sequential number
|      └───── Section number
└────────────  Road number
```

```
2630 - 1
|      |
|      └──── Sequential number
└───────────  Road number
```

Note: Longer collector roads may be broken down into sections, whereas shorter ones may not.

Local Roads

Labeling for local roads is more difficult. Data are filed under first four digits.

General Example

4200-300 Sample from Road 4200-300

Generally, a local road will only have limited sampling. Soil data filed under Road 4200.

Specific Example

Where more than one sample is taken on a local road.

4370-650
4370-651 Both from road 4370-650. Soil data filed under Road 4370.

Exceptional Example	2600-61	Samples for Road 2600-600
	2600-62	Samples labeled this way since there is a Road 2600-601. In addition, Road 2600 does not exist (Road 26 is US 26). Soil data filed under Road 2600.

OCHOCO GEOTECHNICAL ENGINEERING FILING SYSTEM

The primary filing system has two main components under which all information is filed: roads and aggregate sources.

Road files contain all available geotechnical information for the roads on the Forest. This information includes notes, condition surveys, soil data, CBR data, road plans (showing the depth and type of surfacing), photographs, and pavement design calculations.

The road files serve as the primary and original file for all road information. Laboratory data for aggregate crushed for a given road is filed under the appropriate aggregate source. Pavement mix designs are filed under both the road and aggregate source.

Aggregate source files contain all available information for aggregate material sources on the Forest. This information includes notes, photographs, drill logs, development reports, material source plans, air photos, and laboratory information.

In addition, these files serve as the primary place for filing laboratory data on gradations and quality tests that have been run for various projects. Pavement mix designs are filed in both road and aggregate source files.

The secondary filing system includes project files maintained for each timber sale, capital investment, or maintenance project. During the design (or current) phase of a project, soil and other data are collected and maintained in the project file. Following completion of design, the original information is transferred to the road or aggregate source file. Either a summary copy or reference is made in the project file to note where and when the original data were permanently filed. Generally speaking, CBR data should always be filed under roads immediately, with a copy maintained for the project file.

The other secondary files of importance are aggregate and soil files. The aggregate file

contains a summary table of those sources for which unit weight information is available. These include Humphres, Rodded Dry, and Loose Unit Weights. Specific gravity information is noted as well as the gradation (or type) of material used to make the unit weight determination.

The soil file contains a summary table of data on all soils for which CBR information is available. All CBR samples run between May 1, 1978, and November 1, 1980, are included in this table. The table lists other pertinent soil properties that can be used for estimating the CBR of soils which have similar properties. Information is cross-referenced by road, project, and laboratory submittal. This referencing system allows one to determine the location of all samples.

SOILS INVESTIGATION SYSTEM

Project Definition	- Define goals and objectives of project. - Establish scope of project.
File Review	- Gather available information which is on hand in office.
Air Photo	- Gather air photos of area and analyze.
Preliminary Field Work	- Review entire project area on the ground to gain overall picture. - Correlate air photos with field conditions. - Segment road. - Label segments by letter and describe briefly. Examples: S Scab flats M Marsh W Wooded area - old growth, deep soils A Wooded area - new growth
Limited Soil Sampling	- Verify initial work and set definite limits of each segment. Refine descriptions. - Collect "grab" soil samples in ziplock bags from various points. - Label samples using each segment's letter and identify location by station or milepost.
Sample Selection & Collection	- Establish sampling criteria and sample locations. - Field adjust sample locations as needed. - Collect samples--100 lbs. minimum. - Label samples per numbering system. Examples: 41-21, 41-22

Laboratory Testing	- Classify soil by Unified and AASHTO. T 99 optional.
CBR Testing	- Select samples for CBR testing.
Review	- Review CBR test data and soil information. - Field review held as needed. - Resegment road as needed.
Secondary Sampling	- Collect additional soil samples and perform necessary tests, if needed.
Analysis	- Review test data. - Select soil support value for each segment.
Construction	- Monitor project during construction.

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Reader's Notes

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