Standard and Testing Procedures in Laboratory for Coal Log Fabrication

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1. INTRODUCTION

The quality of coal logs for transportation by CLP (Coal Log Pipeline) is determined mainly by the water resistance and wear resistance of the coal logs under conditions similar to those encountered in future commercial CLP. There are many factors that affect the quality of coal logs. They must be clearly specified and controlled in order to insure that good quality coal logs and consistent results are produced.

The purpose of this document is to specify the procedures used in manufacturing and testing coal logs at the Capsule Pipeline Research Center (CPRC), University of Missouri--Columbia and Rolla campuses. All researchers on the two campuses must follow these procedures so that test data are reproducible on different days by different experimenters, and test results can be properly compared between researchers.

2. COAL AND COAL MIXTURE PREPARATION

2.1 Coal

Unless otherwise justified, the following coals should be used:

Bituminous coal: Use the coal from the Mettiki Mine in Maryland, MAPCO Coal Company.

Sub-bituminous coal: Use PRB (Powder River Basin) coal from the Antelope Mine in Wyoming.

2.2 Top Size and Particle Size Distribution

The standard top size of coal particles for making 1.9-inch-diameter coal logs is -30 mesh (0.6 mm maximum). For larger coal logs, the top size should be increased in proportion to the coal log diameter, approximately. For instance, the top size of coal particles for making 5.4-inch-diameter coal log should be -10 mesh (1.8 mm Maximum). In addition, the particle size distribution at a given top size is also an important factor that affect coal log quality. It is believed that particle size distribution which gives the maximum packing density will produce good quality coal logs. The particle size distribution for maximum packing density is calculated by:

$$\Psi(d) = (d/d_{max})^{0.5} \quad (1)$$

where $\Psi(d)$ is the fraction of coal particles smaller than a given particle size **d**. In the standard case for 1.9-inch coal logs, $d_{max} = 0.6$ mm.

In order to get coal particles to possess -30 mesh top size, crushing of the as-received coal is necessary. On the Columbia campus, the as-received coal can be crushed by using the small hammer-mill located at the dirty room of Coal Log Fabrication Laboratory, CPRC. Mettiki coal crushed to -30 mesh by the Gundlach Company is also available. For standard coal logs, coal particles crushed by the Gundlach Company should be used.

The particle size distributions of Mettiki coal crushed by the CPRC hammer mill and the Gundlach Company were studied. The results are listed in Table 1. A comparison of the particle size distributions of Mettiki coal crushed by the CPRC hammer-mill, the Gundlach Company, the Retsch cross-beater mill, and that for the maximum packing density is given in Fig. 1. The differences in coal log quality produced by using the CPRC hammer mill crushed coal and the Gundlach Company crushed coal are shown in Table 2 (Yang, 1996).

Table 1. Particle size distributions for CPRC crushed and Gundlach crushed Mettiki coal

Mesh No.	Particle Size (mm)	CPRC (%)	Gundlach (%)
30-40	0.600	6.46	3.84
40-50	0.425	16.56	6.74
50-60	0.300	30.56	9.26
60-80	0.250	13.52	14.33
80-100	0.180	5.38	7.73
100-150	0.150	11.41	17.47
150-170	0.104	1.45	3.81
170-200	0.088	6.24	6.41
200-Pan	0.075	8.42	30.41
Total		100.00	100.00

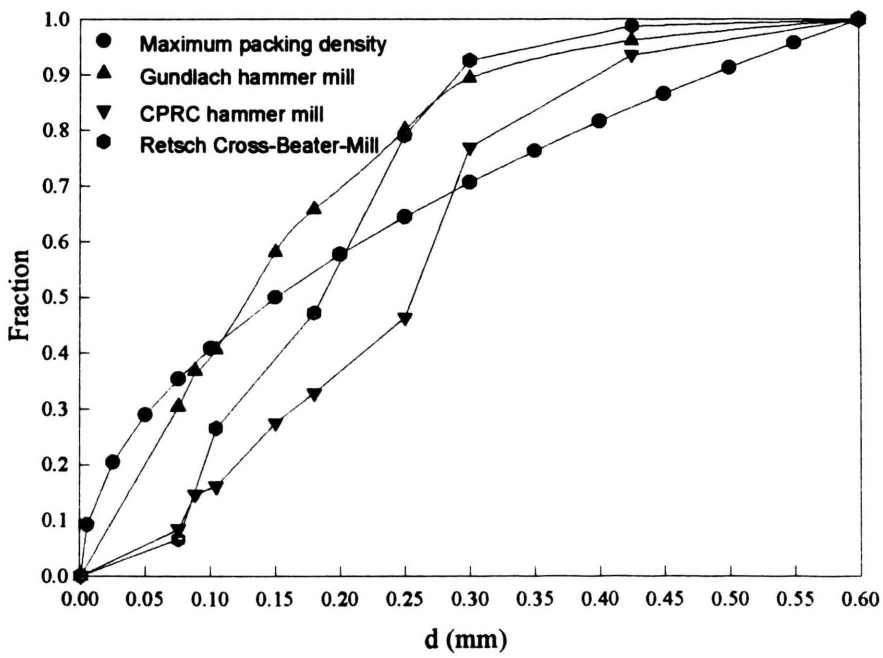

Figure 1. Comparison of particle size distributions of Mettiki coal

Table 2. Weight loss of coal logs with different coal (Mettiki) particle size distributions

Particle Size Distribution	CPRC Hammer Mill	Gundlach Company	
Binder (%)	3	3	3
Moisture Content (%)	4	4	8
Weight Loss after 350 cycles (Top in Front)	4.5%	5.0%	4.4%*
Weight Loss at 350 cycles (Bottom in Front)	–	4.0%	3.3%

* Three coal logs were used in each test. Only one coal log of the three survived the circulation test. The other two broke before 350 cycles were reached.

2.3 Moisture calculation and determination

The moisture content of the coal-binder-water mixture needs to be tightly controlled. Follow these steps when preparing the mixture:

1. The coal crushed by the Gundlach Company to -30 mesh can be used directly for making coal logs without screening. If CPRC hammer mill crushed coal is used in the test, after grinding the as-received coal, sieve the coal particles by using No. 30 mesh screen for 15 minutes. Use the portion that is under the 30 mesh screen.

2. Measure the initial moisture content m_i of the coal (- 30 mesh) using the moisture balance. The procedure for measuring moisture content locates next to the moisture balance. Moisture content m_i must be measured whenever a new batch of coal mixture is prepared. Even for the same batch of coal, do not assume m_i to be constant.

3. Measure the weight of the coal sample W_c in grams (gm).

4. Determine the total dry weight of coal W_{dc}:

   W_{dc} (gm) = W_c (1 - m_i)

For example, if three coal logs are going to be made in one batch and each coal log takes 200 grams of mixture, then $W_c = 590$ gm and $m_i = 2\%$, $W_{dc} = 590\times(1-0.02) = 578.2$ gm.

5. Determine the dry weight of the binder needed.

   If the targeted binder concentration is b based on the dry weight of coal, then the dry weight of the binder needed is:

   W_{db} (gm) = b W_{dc}

   For instance, if in the standard asphalt concentration $b = 1\%$ and $W_{dc} = 578.2$ gm, $W_{db} = 0.01\times578.2 = 5.782$ gm.

6. Determine the total weight of the binder including water (Orimulsion or asphalt emulsion):

   $W_b = W_{db}/(1-m_b)$

   where m_b is the moisture content of the binder. For undiluted Orimulsion, the moisture content specified by the manufacturer is $m_b = 0.3$. Therefore, $W_b = 5.782/(1 - 0.3) = 8.26$ gm and the Orimulsion is $8.26 \div 578.2 \times 100\% = 1.429\ \%$.

7. Determine the dry weight of the coal-binder-water mixture:

   $W_{dm} = W_{dc} + W_{db}$

8. Determine the weight of water that should be in the coal-binder-water mixture:

   $W_w = m_t W_{dm}/(1 - m_t)$

   where m_t is the targeted moisture content of the final mixture. Unless otherwise mentioned, use $m_t = 8\%$ for the Mettiki coal crushed by the Gundlach Company and use $m_t = 38\%$ for the PRB coal.

9. Determine the weight of water to be added to the coal and binder.

Because W_w includes the water in the coal and binder, the actual amount of water needs to be added to the mixture is:

$W_{add} = W_w - m_i W_c - m_b W_b$

2.4 Mixing of Coal with Binder and Water

Two kitchen mixers are available in the Coal Log Fabrication Laboratory, UMC. One (Hobart) has the capacity of about 30 kg and the other one (Ultra Power, KitchenAid Inc.) has the capacity of around 0.8 kg. Use the small mixer if the coal mixture in one batch is less than 700 g.

1. Weigh W_c grams of coal in Container 1 (e.g. a clean mixing bowl). Remember to tare the weight of the container first.
2. Use Container 2 to weigh the amount of water needed based on the W_{add} calculated above. Use a balance that gives at least 0.1 g accuracy.
3. Use a small disposable plastic cup to weigh the amount of Orimulsion needed based on W_b calculated above. Use a balance that gives at least 0.01 g accuracy.
4. Pour a portion of the water measured in Step 2 into the small plastic cup that contains the Orimulsion. Carefully stir the Orimulsion and water to mix them thoroughly.
5. Pour the binder-water mixture from the small plastic cup into Container 2. Then stir thoroughly and carefully.

6. Pour the binder-water mixture from Container 2 into the center of Container 1. Slowly hand mix the binder-water mixture with the coal using a big spoon for about one minute.

7. Pour the hand-mixed mixture into the mixing bowl. Cover the mixing bowl with the plastic cover. Lock the mixer in its working position. Turn on the mixer at the lowest speed. The recommended mixing times are given below:

Table 2. Recommended mixing time

Moisture (%)	Mixing Time (minutes)
20	5
15	8
8	10
<5	15

8. Check the actual moisture content of the mixture.
   After mixing, measure the actual moisture content m_t of the coal-binder-water mixture using the moisture balance. Store the mixed materials in a sealed container. The moisture content of each batch of mixture needs to be measured again immediately before compacting coal logs.

2.5 Tempering of Coal Mixture

After mixing with water and binder, if the coal mixture is stored at room temperature in a seal container for certain time before compaction, then this storing time is referred as tempering time. According to Bahr and Luecke (1996), no effect of tempering time have been noted on coal log quality. However, for a large batch (10 to 15 kg/batch) or very low moisture (4 to 8% for Mettiki coal) mix, tempering the coal mixture for 24 hours before compaction is recommended. Make sure that the coal mixture is in a sealed container during tempering. Otherwise, the moisture content may change with time.

3. COAL LOG COMPACTION

3.1 Mold and Pistons

The molds and pistons that are currently available in the Coal Log Fabrication Laboratory (Columbia campus) are listed in Appendix A. The standard mold for compacting 1.9-inch coal logs is **No. 9 Mold** without wall lubrication. The standard pistons are flat-ended, stainless steel pistons **(No. 9 pistons)**. Standard pistons to produce beveled logs will be used in the future.

3.2 Loading of the Coal Mixture

The hydraulic press used for coal log compaction is showed in Fig. 2. Lower the platform to its lowest position. Put the bottom alignment head on the platform (Fig. 3). Carefully insert the bottom piston into the alignment head, and secure the piston using the screw. If the moisture content of the coal mixture is higher than 8% on wet weight basis for Mettiki or 20% for PRB coal, seal the clearance between the piston and the head with grease so that water cannot leak into the alignment head. Put the supporting block on top of the bottom alignment head and then set the mold on top of the supporting block. Adjust the position of the supporting block and the mold so that the vertical guiding surfaces aligned well with the sides of the bottom alignment head and the mold (Note: It is important to have the mold and pistons well aligned since misalignment will damage the pistons, mold, and/or the machine).

Load coal mixture carefully into the mold by using a funnel. For the standard 1.9-inch coal logs (Mettiki coal) having an aspect ratio of 1.7, coal mixture of 200 gm is used for making one coal log. After loading the coal mixture, clean the inner surface of the orientation block carefully. Push **the bottom alignment head** into the marked circle so that the whole aligned unit is located right under the upper piston. The upper piston should be secured with screws on the upper alignment head.

3.3 Heating of Coal Mixture

If higher than room temperature compaction is required, the coal should be heated in one of the following two alternative manners:

<u>A. Mold Heating Method:</u>

1. Insert a thermocouple into the mold and hook up the electric power to the heaters.
2. Set the heater controller to 97°C or desired temperature and turn on the power.
3. Let the mold and piston heat until the controller starts to cycle. Red light turns on and off.
4. Load the coal mixture as described above. Let the mold and mix set for 20 minutes so the mix is at the temperature targeted.

B. Pre-Heating Method:

Coal is preheated in a closed container in an oven to the desired temperature. Then the coal is quickly placed into the mold and compacted. The mold should also be preheated to the same temperature.

3.4 Compaction and Ejection

If the hydraulic press showed in Fig. 2 is used for the compaction, the standard compaction procedure is as following:

1. Check the air pressure gauge (Part 27 in Fig. 2), the air pressure should be around 25 psi under normal conditions. Otherwise, do not use the compaction machine.
2. Check loading of coal mixture, mold and piston positions, and computer settings before starting the press.
3. The upper piston should be secured with both screws located on the upper alignment head.
4. Close the unloading valves (the big wheel and the small knob, Part 30 in Fig. 2).
5. Turn on the hydraulic press by pushing the **START** button (Part 35 in Fig. 2). Open (turn counterclockwise) the big loading wheel (Part 28 in Fig. 2). After the big loading valve is open, the platform will move up. Wait until you hear a click sound; then close the big loading valve. The platform (Part 10 in Fig. 2) will hold its position.
6. Lower the sensitive platen slowly (machine crosshead, Part 9 in Fig. 2) by pushing the **DOWN** button that controls the electric motor until the upper piston is about 2 mm above the entrance of the mold.

7. Before lowering the upper piston further, check and adjust the position of the mold again. Then use the **DOWN** button to lower the upper piston **very slowly** and allow it to slide smoothly into the mold for at least two inches. Before compaction, slightly rotate the mold to see if the upper piston is touching the mold.

8. Set the displacement sensor rod so a reading of about 6.0 is shown on the computer screen.

9. Start the computer to record data.

10. Slightly loosen the big unloading valve (Turn counterclockwise first then close it but **not tightly**).

11. Turn the **Micrometer Control Loading Valve** counterclockwise for one full turn then wait for the load to increase by itself. No load can be read at the first 5 to 10 seconds then the load will increase very rapidly. Once the load reaches 52,000 lbs of force, open the big unloading valve quickly to release the loading. The whole cycle takes about 45 sec.

12. Close (turn clockwise) the **Micrometer Control Loading Valve** and raise the upper piston high enough so that the mold, supporting block and the bottom alignment head can be pulled out together.

13. Lift the mold and put it on the ejection block, then push the unit under upper piston

14. Align the mold with the upper piston again.

15. Slide the upper piston into the mold very slowly using the **DOWN** button until the piston touches the top of the coal log (the piston will not move any further).

16. Put the foam rubber pad under the mold.

17. Close (turn clockwise) the big unloading wheel and open (turn counterclockwise) the big loading wheel for 1/2 turn.

18. Wait until the coal log was ejected onto the foam pad.

19. Close (turn clockwise) the loading valve, open (turn counterclockwise) the unloading valve quickly, and stop the computer recording.

20. Remove the coal log and record its weight and dimensions.

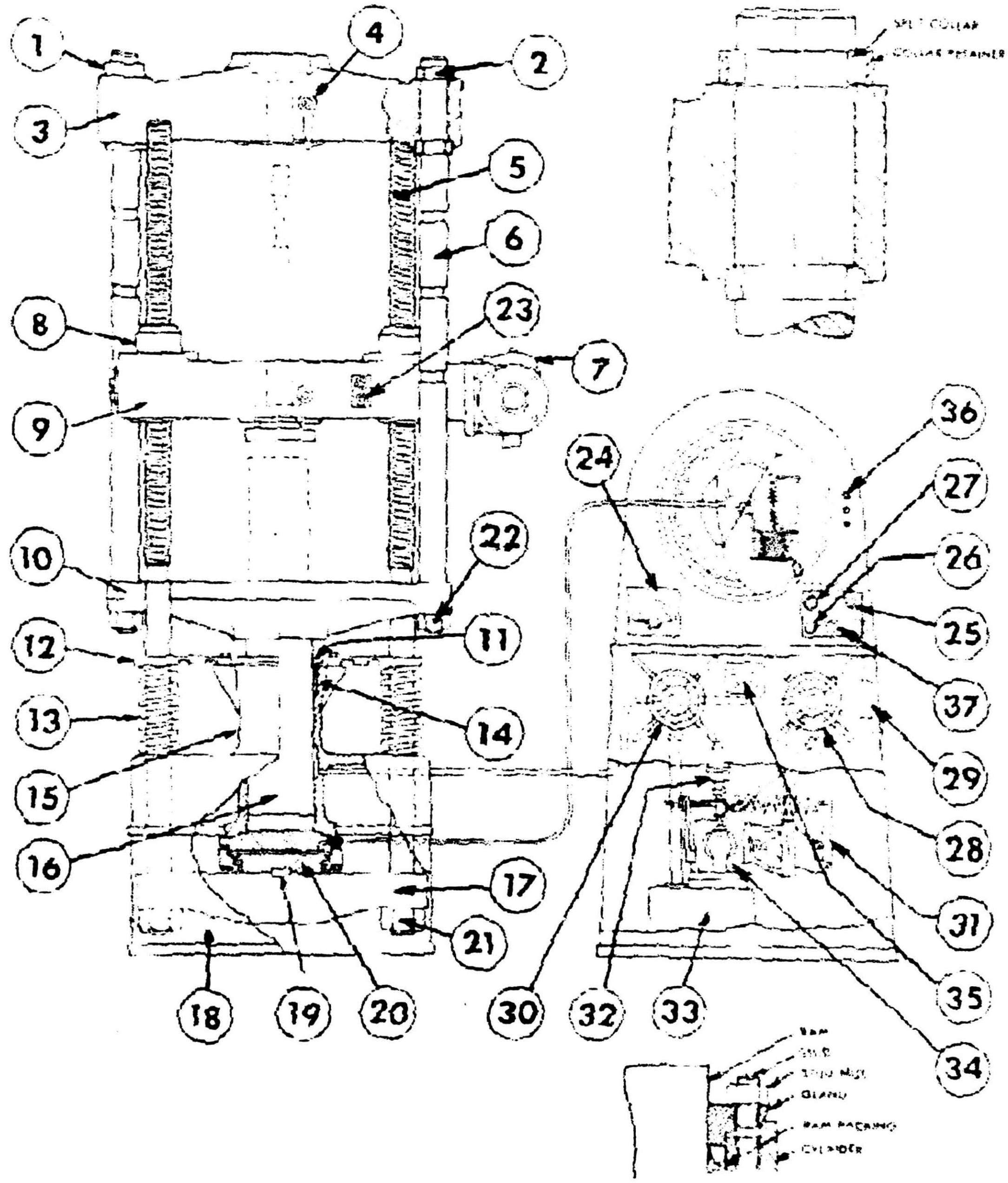

Fig. 2. Hydraulic press for coal log compaction (Baldwin Tate-Emery Universal Testing Machine)

BALDWIN-TATE-EMERY UNIVERSAL TESTING MACHINES

Part list

1. Collar Retainer
2. Split Collar
3. Top Platen
4. Operating Grip Handle
5. Tension Screws
6. Compression Columns
7. Platen Adjusting Motor
8. Backlash Eliminator
9. Sensitive Platen
10. Table
11. Packing Gland (for Cylinder)
12. Flexure Plate
13. Initial Load Spring
14. Hydraulic Packing
15. Cylinder
16. Ram
17. Bottom Platen
18. Base
19. Centering Plug
20. Capsule
21. Nut (Bottom of Screws)
22. Nut (Bottom Compression Columns)
23. Push Button Control Platen Adjusting Motor
24. Pacing Disc Control
25. Air Shut-off Valve
26. Low Range Shut-off Valve
27. Air Gauge
28. Micrometer Control Loading Valve
29. Air Intake and Filter Valve
30. Unloading Valve
31. Automatic Pump Leakage Compensating Control
32. Relief Valve
33. Oil Reservoir
34. Motor driven Radial Piston Pump
35. Starting and Stopping Switch
36. Zero Indicator Adjustment Knob
37. Range Selector

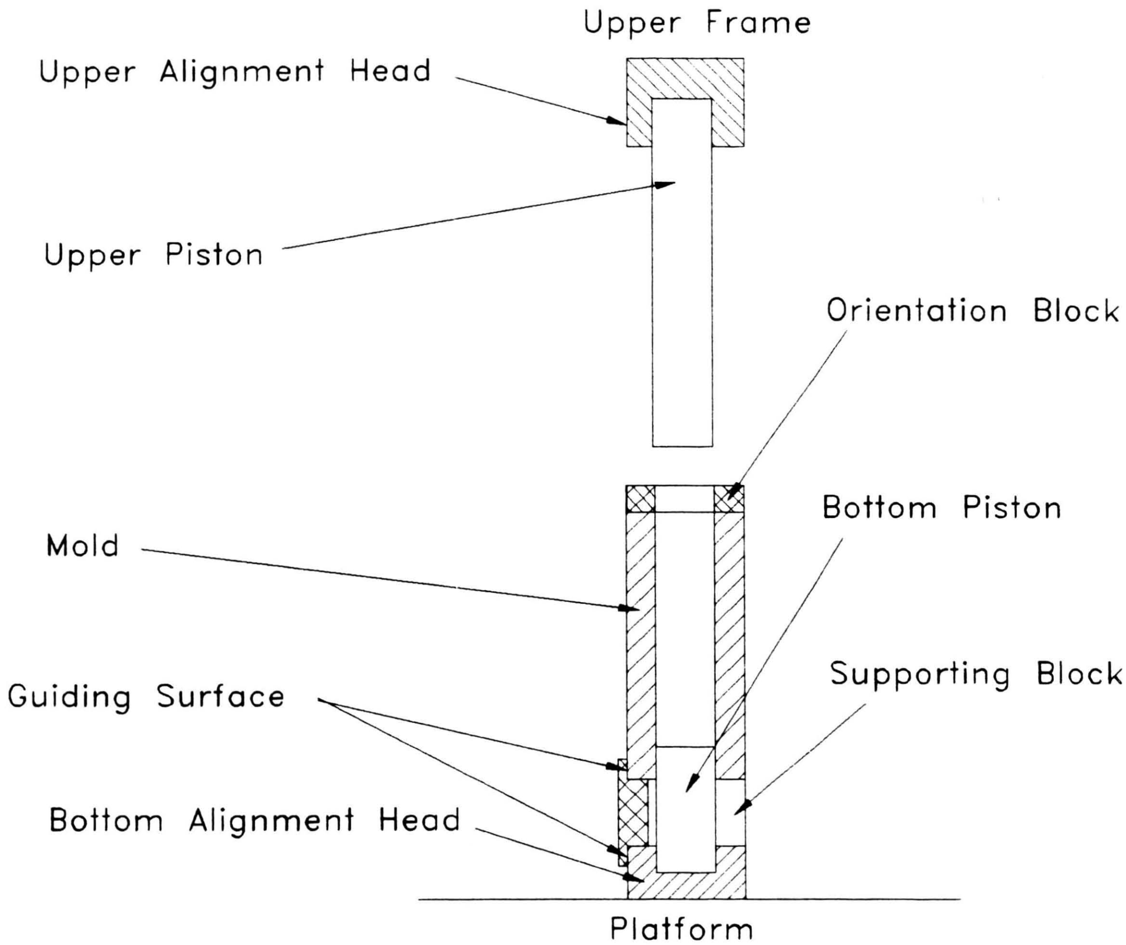

Figure 3. Mold and piston alignment

3.5 Computer Data Acquisition

The data acquisition software used for collecting data during compaction and ejection is QuickLog PC (Strawberry Tree, Sunnyvale California). For detailed instruction on how to use the software, consult the user's guide. For routine data collection, follow these steps:

1. Turn on the computer next to the hydraulic press.
2. Type "**cd ql**" and wait until the QL root directory appears on the screen. Type "**go**" and wait for the QuickLog screen to appear.
3. Double-click the data file icon and change the name of the data file that you want to save.
4. Before starting compaction, hold down the right mouse button and choose **Enable All** to start collecting data. After ejecting coal log, hold down the right mouse button and choose **Stop All** to stop data acquisition.
5. You must remember to change the file name before compacting the next coal log. Otherwise, the new data will overwrite the old one.
6. It is strongly recommended that you create a subdirectory of your own and save all your files under your subdirectory.
7. To create a subdirectory, go to **DOS** first. From **DOS** type **"cd log".** Then type "**md *****". ******* here represents the name of the subdirectory that you have selected.

3.6 Coal Log Data Collection

After each coal log has been made and ejected, the following data should be recorded using the data sheet in Appendix B:

1. Mark the coal log properly to indicate the top and experimental ID.
2. Weigh the coal log and record the weight in grams.
3. Measure the diameter of the coal log using a caliper at three different position (top, middle, and bottom). Record the diameters in the same data sheet.
4. Measure the length of the coal log using a caliper at three different position (e.g. rotate 120° after each measurement). Record the lengths in the same data sheet.
5. Reject the coal log if there are severe cracks on the surface.

4. CURING OF COAL LOGS

Curing refers to setting compacted coal logs in air at room temperature for certain time before or after water absorption test. The effect of curing time on coal log quality has been studied by Dr. Wilson's group at the University of Missouri-Rolla. It was found that when coal logs were cured from 0 to 24 hours the tumbling weight loss was reduces from 7.5 to 2.4. Because of curing effect, it is recommended that no curing in air should be allowed in the standard test. For both room temperature and high temperature (97°C) coal logs, the only time that coal logs can stay in air after ejection is the time needed for dimensional and weight measurements. After these measurements are made, the coal logs go to water absorption test immediately. In the high temperature case, if the temperature of the coal log is to high too be handled,

5. WATER ABSORPTION TEST

Right after compaction, all coal logs compacted should subject to a water absorption test in 500 psi water for one hour.

5.1 Water Absorption Test Apparatus

The water absorption test apparatus for 1.9-inch coal logs is given in Fig. 4. The system contains a high-pressure hydraulic (oil) pump, a pressure gage, an upstream control valve, a downstream control valve, a water supply switch valve, 12 ball valves, and six Plexiglas cells (pressure vessels). Normally, one coal log is tested in one cell but it is possible to test three coal log in each cell simultaneously.

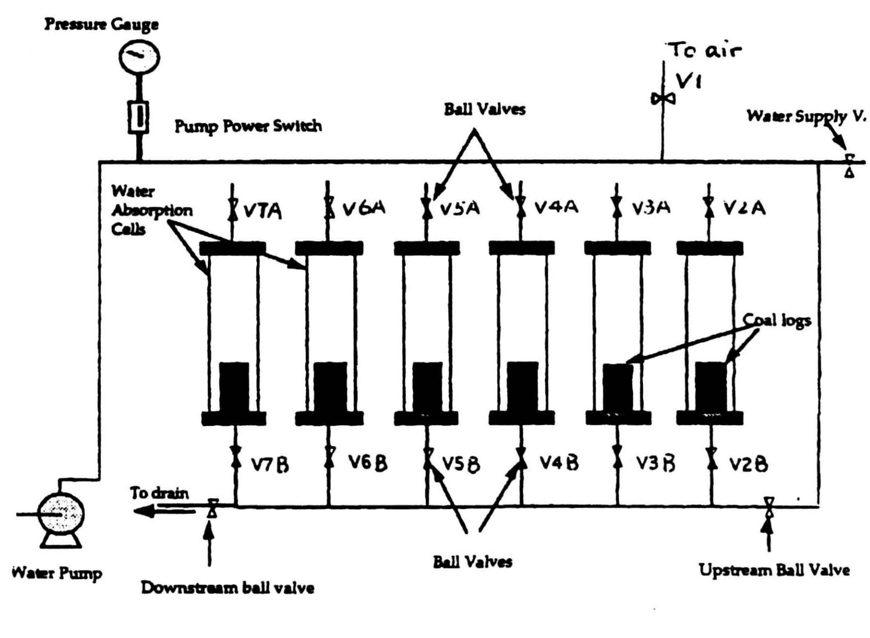

Fig. 4 Water Absorption Test Apparatus (Merayyan, 1995)

5.2 Water Absorption Test Procedures

1. Close the down stream valve and open the upstream valve. Open the upstream water supply valves and expel the air out by opening then closing the ball valve (V2B to V7B) located at the bottom of each cell.
2. Place the coal logs in the cells and tighten the bolts. Make sure that o-ring seals are properly attached to both ends of the cell.
3. Open the ball valves (e.g. V2B, V3B...) located at the bottom of the cells that contains coal logs. Allow the water to enter the cells at an appropriate speed. Close the ball valves (e.g. V2A, V3A...) located on the top of the cells when the cells are full. Then close the water supply valves.
4. Close Valve 1 and turn the pump power switch on to allow the water in the cells to be pressurized. After reaching 500 psi., the pump will stop automatically.
5. After one hour, the pressure is released by opening the release valve (Valve 1). Then open the downstream ball valve, the ball valves (e.g. V2B and V2A) located at the bottom and the top of the cells.
6. After the water in the cells is drained, loosen the bolts and remove the coal logs from the testing cells.
7. After completion of the water absorption test, weigh the coal logs and measure the weight and dimensions (diameter and length) of each coal log immediately. Normally, the coal logs tested for water absorption will be stored in atmospheric pressure water at room temperature for less than 24 hours before circulating in the pipe.

6. WEAR RESISTANCE TEST

6.1 Circulation Loops

Currently, two steel loops, Line 2 and Line 3, are available for coal log wear resistance tests. Line 2 has a inner diameter of 2.155 inch and a total length of 76.10 feet. Line 3 has a diameter of 2.161 inch and a total length of 79.05 feet. Figs. 5 and 6 are Line 2 and Line 3 used for coal log wear tests. For standard coal logs, Line 2 should be used for the wear resistance test.

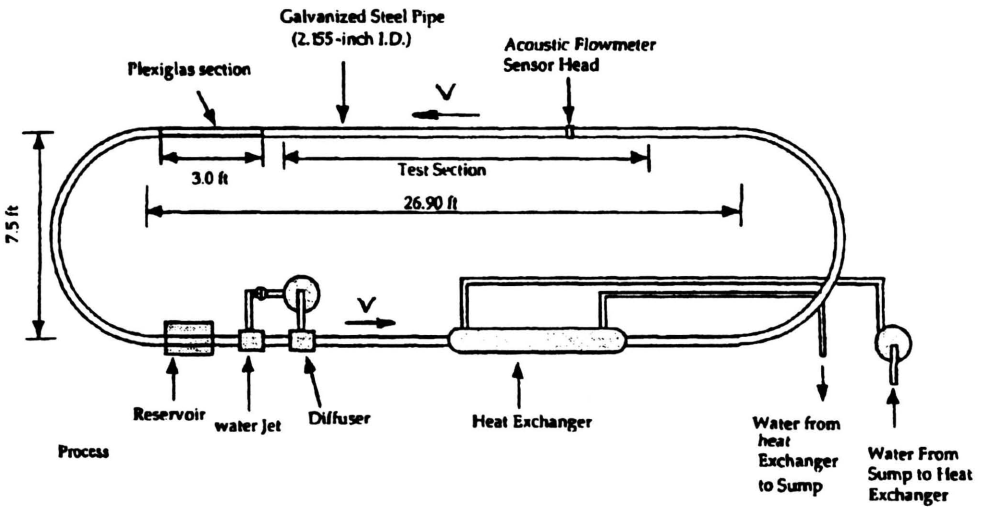

Figure 5. Circulation loop -- Line 2 (Merayyan, 1995)

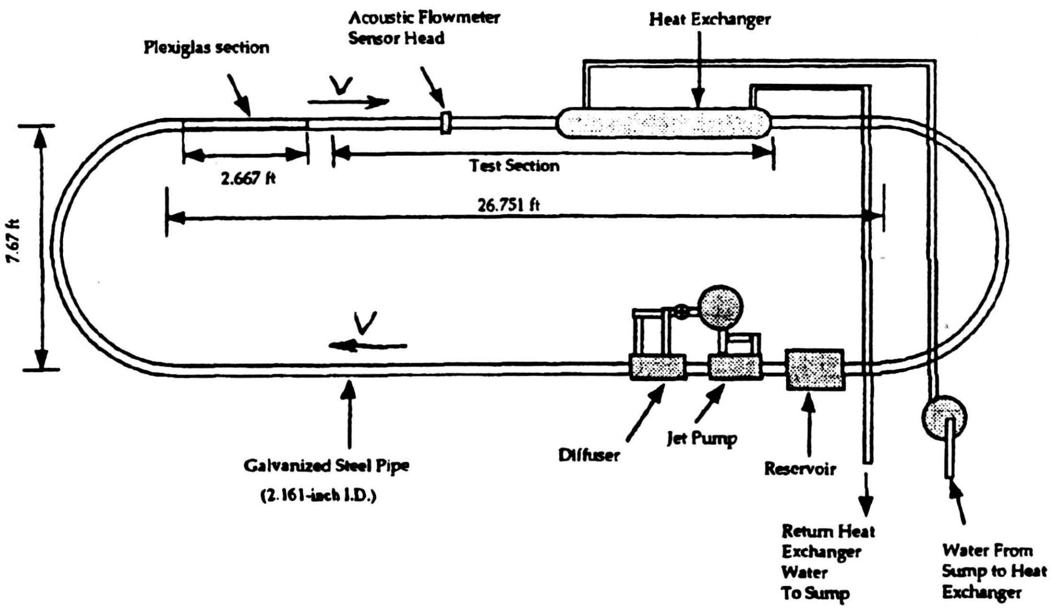

Figure 6. Circulation loop -- Line 3 (Merayyan, 1995)

6.2 Circulation Velocity Calculation

The lift-off velocity (V_L) of coal logs in water is predicted by the following equation (Liu, 1982):

$$V_L = 7.2\sqrt{|S-1| a\, g\, k(1-k^2) D} \tag{2}$$

where S is the density ratio between the coal log and the bulk fluid (ρ_c/ρ_b), ρ_c is the density of the coal log before wear test, ρ_b is the bulk-fluid (water) density, a is the aspect ratio of the log (i.e. the log length to log diameter ratio), g is the acceleration due to gravity, k is the diameter ratio of the coal log and the pipe, and D is the inner diameter of pipe. The inner diameter of pipe is 0.1796 ft for Line 2 and 0.18 ft for Line 3.

A sample lift-off velocity calculation is shown in Ex. 6.2.1.

Ex. 6.2.1 Given a coal log with S = 1.2, k = 0.75, and a = 2.0, determine the lift-off velocity in a 2-inch pipe.

$$V_L = 7.2\sqrt{(1.2-1)(32.152\frac{\text{ft}}{\text{sec}^2})(2.0)(0.75)(1-0.75^2)(2.0\text{ in})(\frac{1\text{ft}}{12\text{in}})}$$

$$V_L = 6.038 \text{ ft/sec}$$

The standard circulation velocity V for wear resistance test is 85% V_L. In order to monitor the velocity during a wear test, the circulation velocity is converted into voltage using the following equation obtained by Chang (1994):

$$V\ (\text{ft/s}) = 3.1642 \text{ voltage} - 4.0832 \quad (3)$$

Note that Eq. (3) is based on calibration of an acoustic flowmeter in Line 2. It should be recalibrated periodically, and should be different for Line 3 than for Line 2.

6.3 Circulation Test Setup

<u>A. Loop setup</u>

1. Make sure the reservoir is clean. If not, rinse the reservoir first. The drainage should be connected to a filter tank to filter out the solids (coal particles) before the water is discharge into the drain of the Hydraulic Laboratory.
2. Check the jet-pump filter and the drain filter periodically. Clean the filters when they are dirty or clogged.
3. Turn on the heat exchanger.
4. Fill the reservoir until it is 2/3 full. Open the small valve on the diffuser to expel the air.

5. Turn on the water pump (use the switch marked Line 2).

6. Slightly open the valve controlling the water jet and observe the pressure change.

7. Once the flow has reached a steady state go to the computer.

B. Computer setup

The circulation velocity is monitored by an IBM PC portable computer, equipped with a Lab Master (Model TM-PGH, Scientific Solution Inc.) data acquisition board. The output voltage from the flow meter is recorded and plotted on a high speed record chart. The steps for setting up the computer are:

1. Turn on the hard drive and the computer.

2. Type "**cd asystant**" then type "**asystant**".

3. Select **Continue,** then press **Enter**.

4. Select **Acquire**, then press **Enter**.

5. Select **High Speed Record Chart.**

6. Go to **Edit Data Acquisition.**

7. Change **number of channel** to **1**.

8. Change **start channel** to **11**.

9. Change **acquisition rate** to **1000**.

10. Press **Esc** and wait for the chart to appear.

11. Press any key (except **Esc**) to start plotting, then **F5** to read the voltage.

12. Adjust the flow rate by using the valve. Make adjustment based on the reading on the computer until the calculated voltage has been reached.

13. Press **Esc** to check the voltage at any time needed.

6.4 Weight Loss Data

Once the flow rate has been set to the targeted one, the loop is ready for circulation test. The following steps should be followed for the circulation test:

1. Dry the coal log surface with a paper towel. Weigh the coal logs one by one and record their initial weight in Table 4.
2. Check the label on each coal log.
3. Insert the coal logs with the top end towards the front. Leave about 1 ft spacing between coal logs.
4. After putting all the coal logs into the pipe, start timing using a stop watch and check the voltage readings on the computer.
5. Adjust the flow rate using the valve if necessary.
6. Take the coal logs out according to the time intervals given in Table 4, weigh and record the weight of each coal log as in Step 1.
7. Repeat Steps 3 to 6 until the end of circulation (e.g. two hours).
8. If any of the coal log breaks severely during the circulation, take it out and take note on Table 4. Continuously circulate the others.
9. When the circulation has been finished, take out the coal logs, clean the pipe carefully, and turn off the heat exchanger, water pump and computer.
10. Observe the wear pattern on the coal logs and record the pattern in Table 4.
11. Clean the working place.

12. Do not leave the circulated coal logs in the Hydraulics Laboratory. Keep them for tensile strength testing, picture taking, or other purposes.

7. SPLITTING TENSILE STRENGTH

The splitting tensile strength test for coal logs is adopted from a standard procedure (ASTM C496-90) for splitting tensile strength of cylindrical concrete specimens. The splitting tensile strength test can be conducted immediately after coal logs are compacted. Since this is a destructive test (coal logs will be damaged during the test), it is recommended that the test be performed immediately after coal log wear test. Before testing, the coal log diameter and length need to be measured. Take three measurements for each dimension at three different position. The splitting tensile strength testing apparatus is given in Fig. 7. Center the specimen in the apparatus and rotate the specimen until the air gap between the specimen and the bearing strips is minimized to ensure that the load is applied uniformly along the length of the cylindrical surface. Apply a load at the rate of 5 to 15 lbs/sec until the specimen fails.

The splitting tensile strength, which is the theoretical tensile stress across a failure plane just prior to failure, is calculated as follows:

$$T_s = \frac{2P}{\pi D_c L_c} \alpha \tag{4}$$

where

T_s --- splitting tensile strength (psi),

P --- failure load (lbf),

D_c -- specimen diameter (in), and

L_c -- specimen length (in).

α -- correction factor

Equation (4) was developed based on $L_c/D_c = 2.0$. The factor in Eq. (4) is a correction factor for short logs. For coal logs with $L_c/D_c = 1.6$ to 2.0 , $\alpha = 1.0$ can be used.

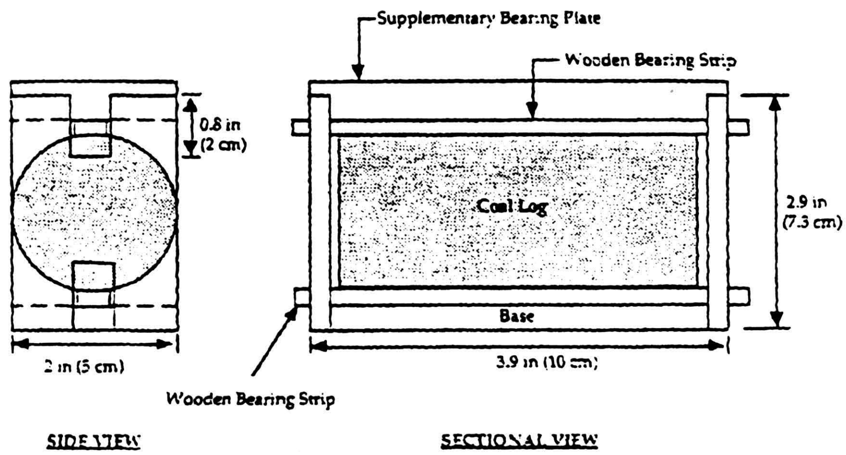

Figure 7. Splitting tensile strength apparatus (Chang, 1994)

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Appendix A:

Mold Inventory

Updated 03/08/96

1. Single-Piece Mold (Cylindrical)
    1.75″ inside bore diameter
    11" length
    1° taper in bottom 3″
    Stainless steel and no plating of the bore
    120 volt plugs
    Two 500 watt band heaters
    Note: No heater. Oldest existing mold in use.

2. Split Mold (Rectangular)
    1.75″ inside bore diameter
    9″ length x 3.44″ x 3.75″
    10 bolts (no nuts) required
    Mild steel and no plating of the bore
    240 volt plugs
    Two 400 watt strip heaters
    Note: Previously repaired for bulging split

3. Split Mold (Rectangular)
    1.75″ inside bore diameter
    8.875″ length x 4″ x 4″ width
    10 bolts (no nuts) required
    Mild steel with chrome plated bore
    240 volt plugs
    Two 400 watt strip heaters
    Note: Needs new electrical wires
    Bulged slightly in middle, may need to be repaired

4. Split Mold (rectangular)
    1.75″ inside bore diameter
    9" length x 3.44″ x 4″ width
    10 bolts and 10 nuts required
    Mild steel with chrome plated bore
    240 volt plugs
    Two 400 watt strip heaters
    Modified for vacuum use
    Note: Currently used only for vacuum experiments
    Chrome plating flaking off

Previously repaired for bulging split

5. Single-Piece Mold (Rectangular)
 1.91″ inside bore diameter
 9″ length x 3″ x 4″ width
 1° taper in bottom 3″
 Mild steel with chrome plated bore
 Note: Currently without heaters

6. Single-Piece Mold (Cylindrical) -- **out of service due to damage**
 1.91″ inside bore diameter
 12″ length x 3.5″ outside diameter
 1° taper in bottom 3″
 Stainless steel and no plating of the bore
 240 volt plugs
 Two 750 watt band heaters
 Note: Mold was severely damaged during fast compaction and cannot be fixed.

7. Split Mold (Rectangular)
 1.91″ inside bore diameter
 10" length x 4″ x 4.5″ width
 10 bolts (no nuts) required
 Mild steel with chrome plated bore
 240 volt plugs
 Two 400 watt strip heaters

8. Single-Piece Mold (Cylindrical) -- **out of service due to damage**
 1.91″ inside bore diameter
 11" length x 3.5″ outside diameter
 1° taper in bottom 1.5″
 410 stainless steel and no plating of the bore
 240 volt plugs
 Two 750 watt band heaters
 Note: Mold was damaged during fast compaction and fixed with a larger diameter.
 The current identification for the fixed mold is No. 8A.

8A. Single-Piece Mold (Cylindrical) -- **out of service due to damage**

 1.962″ inside bore diameter
 11" length x 3.5″ outside diameter
 1° taper in bottom 1.4″
 410 stainless steel and no plating of the bore
 240 volt plugs
 Two 750 watt band heaters
 Note: Mold will be used only for studies without wall lubrication.

9. Single-Piece Mold (Cylindrical)

1.91″ inside bore diameter
12.05" long x 3.5" outside diameter
R0.124" rounded exit at the bottom
440C stainless steel heat treated and no plating of the bore
Note: to be used for making standard coal logs

10. Single-Piece Mold (Cylindrical) -- **out of service due to damage**

1.955″ inside bore diameter for top 1.25″
12″ long x 3.75″ outside diameter
0.012"/foot taper for middle 8"
1° taper for bottom 2.75″
2.060″ inside bore diameter at the bottom
Stainless steel with chrome plated bore
Note: The current identification for the fixed mold is No. 10A.

10A. Single-Piece Mold (Cylindrical)

2.016″ inside bore diameter for top 1.25″
12″ long x 3.75″ outside diameter
2.079″ inside bore diameter at bottom
Stainless steel and no plating of the bore
Note: Currently without heaters

11. Single-Piece Mold (Cylindrical) -- **going to be made**

1.91″ inside bore diameter
12.05" long x 3.5" outside diameter
R0.124" rounded exit at the bottom
440C stainless steel heat treated and no plating of the bore
Note: to be used for Dr. Gunnink's group

Appendix B. Coal Log Data Sheets

Table 3. Coal log weight and dimension data sheet

Date:	Name:			Experiment ID:					
Coal:	Top size:			% binder:			m_i (%) =		
W_c (g) =	W_b (g) =			W_w (g) =			m_t^* (%) =		
Pressure (psi):	Temp(°C):			Mold No:			Pistons:		
Before water absorption									
	Log A			Log B			Log C		
Weight (g)									
Diameter (cm)									
Length (cm)									
After one hour water absorption									
	Log A			Log B			Log C		
Weight (g)									
Diameter (cm)									
Length (cm)									
Right before circulation test									
	Log A			Log B			Log C		
Weight (g)									
Diameter (cm)									
Length (cm)									

Table 4. Circulation data sheet

Date: / /	Log ID:	Note:	
Name:	V_L (ft/s):	85% V_L (ft/s):	Voltage (volt):
Time (min)	Log A	Log B	Log C
0			
5			
10			
15			
20			
30			
40			
50			
60			
80			
100			
120			
140			
160			
180			
200			

Note: Log wear pattern (check all boxes applicable)

- ☐ The coal logs were circulated with their **top** ends in front
- ☐ The coal logs were circulated with their **bottom** ends in front
- ☐ Wear exists mainly on the **top** ends of the coal logs
- ☐ Wear exists mainly on the **bottom** ends of the coal logs
- ☐ Uniform wear on both ends
- ☐ Wear appears uniform around
- ☐ Wear skewed on one side
- ☐ A large piece chipped off. Location of the chip:___________
- ☐ Other noticeable wear pattern (with sketch if applicable):__________