PEPSE® Pulverizer Submodel

Greg Eanes

Duke Power Company

PEPSE Pulverizer Submodel

Abstract

Presently there is no expedient method of modeling a coal pulverizer with PEPSE as there is no discrete pulverizer component. The problem is to accurately model the mixing of coal and air, just as it does in true boiler operation, using the current revision of PEPSE. To do this the model would need to determine the hot air and tempering air flows required to maintain a desired coal-air temperature. Also, the coal-drying process should be represented so that the effects of moisture in the coal and air will be accounted for.

At first glance the process seems easily modeled by using standard mixers. However, there are several idiosyncrasies in PEPSE that pose problems with this approach:

- The specific heat (Cp) of coal that PEPSE calculates is a weighted average of the Cp's of the individual constituents which is not the same as the actual Cp of coal as a whole.
- Direct mixing of coal and air adversely affects the excess air and combustion calculations since any air entering the fuel port is not considered as combustion air.
- Increasing the water content of the coal (in order to model surface moisture) by adjusting the mass fractions of the constituents on the fuel card does not give expected results.

As a solution an indirect approach using operations and controls is used. The mixing process is simulated via operations to obtain a true coal-air temperature. Then, controls are used to determine the air flow rates (hot air and tempering air) to get a desired coal-air temperature. Surface moisture is input from a separate source, then mixed with the coal.

This model gives realistic results for various proportions of hot air and tempering air and moisture content. For further applications this submodel can be inserted into a complete performance mode boiler model to determine the dry gas loss effects of lowering coal-air temperature and the effect on boiler efficiency due to moisture in the coal.

Introduction

In the process of developing a performance-mode boiler model for Duke Power's Cliffside 5 unit, it was necessary to determine the amount of tempering air needed for the given design conditions. This quantity of tempering air depends on the desired temperature of the coal-air mixture as well as other factors: tempering air conditions, hot primary air conditions, and the condition of the coal.

The purpose of this paper is to develop a pulverizer model that will closely represent the true mixing/drying process found in actual pulverizer operation. Thus, with a handle on the temperature of the coal-air mixture, the proportions of the tempering air and hot air can be determined using PEPSE controls. The example presented is for design conditions at Maximum Continuous Rating (MCR) of Cliffside 5.

The pertinent design conditions are as follows:

- Atmospheric Pressure = 14.7 psia
- Hot Air (exiting preheater) Temperature = 631. °F
- Tempering Air Temperature = 80. °F
- Ambient Coal Temperature = 80. °F
- Maximum Coal Air Temperature = 180 °F

- Air Humidity Ratio = $.013 \dfrac{\text{lbm } H_2O}{\text{lbm dry air}}$
- Coal Mass Flow Rate = 444,000 lbm/hr.
- Excess Air Leaving Furnace = 20%
- Coal Heating Value = 12,000 Btu/lbm
- Ultimate Analysis of Coal:

C	72.0%
H_2	4.65%
O_2	.35%
N_2	1.2%
S	.8%
Ash	16.0%
H_2O	5.0%

Assumption:
The radiation loss equals the heat gain from the motor.

Overview of Pulverizer Operation

The system with which we are concerned is the "direct firing system" illustrated in Figure 1. Coal is introduced from the bunker through the feeder and then is crushed inside the pulverizer. (A cross section of the pulverizer is shown in Figure 2). The forced draft fan pushes ambient air through the preheater where it is heated to approximately 600 °F. This air is mixed with tempering air just before entering the pulverizer where it dries the coal and transports it to the furnace burners. The furnace is a "balanced-draft" type with induced draft fans located downstream of the furnace exit.

The tempering air is mixed with the hot air to prevent fires that could be caused by the high temperature air from the preheaters. It is best to minimize the tempering air flow as this adversely affects boiler efficiency. Therefore, a constant maximum coal-air mixture temperature is maintained that will maximize boiler efficiency and prevent pulverizer fires. This maximum temperature for the Cliffside 5 pulverizers is 180 °F, as the manufacturer recommends.

Model Development

As mentioned earlier there are inherent problems in PEPSE that prevent a straightforward mixing scheme for the coal and air. The PEPSE schematic diagram used in this model is shown in Figure 3. Note that the coal and air are not mixed together, thus avoiding the "combustion air calculation" problem.

To accurately model surface (or free) moisture in the coal, a separate source of water is mixed in with the coal before it enters the fuel port. The percent H_2O specified on the fuel card is considered inherent moisture. This is moisture that is not driven off in the pulverizing/drying process. (In reality a slight amount of this moisture will evaporate; but it is difficult to predict, thus we will assume that none of the inherent moisture is liberated).

The moisture content in the air sources is taken care of by specifying the humidity ratio ($.013 \frac{\text{lbm } H_2O}{\text{lbm dry air}}$).

Therefore, we can consider the coal-air mixture exiting the pulverizer as a mixture of four components: moist tempering air, moist hot air, coal, and surface moisture in the coal.

The coal-air temperature is calculated through PEPSE operations using the following equation from Reference 1:

$$T_{mix} = \frac{\Sigma\ \dot{m}CpT}{\Sigma\ \dot{m}Cp}$$

or specifically,

$$T_{mix} = \frac{\dot{m}_c\ Cp_c\ T_c + \dot{m}_{ta}\ Cp_{ta}\ T_{ta} + \dot{m}_{ha}\ Cp_{ha}\ T_{ha} + \dot{m}_{sm}Cp_{sm}T_{sm}}{\dot{m}_cCp_c + \dot{m}_{ta}\ Cp_{ta} + \dot{m}_{ha}\ Cp_{ha} + \dot{m}_{sm}\ Cp_{sm}}$$

where T = temperature (°F)
$\dot{m}$ = mass flow rate (lbm/hr)
Cp = specific heat (Btu/lbm °F)

and subscripts c = coal
ta = tempering air
ha = hot air
sm = surface moisture in coal

For this calculation the specific heats of the moist air and surface moisture components are obtained by using the "GPTC" operation which gives the Cp as a function of pressure and temperature. However for coal, a constant Cp of .3 Btu/lbm °F is used as found in Reference 1.

One detail that should be noted when using the "GPTC" operations: reference the stream immediately downstream of the source/input component for the pressures and temperatures of the fluid (e.g., use "PP 1" and not "PPVSC 100"). For reasons unknown, PEPSE gives incorrect values of Cp if you use the input variables instead of the calculated variables.

For a listing of the operations used in this example, refer to the PEPSE input file shown in Figure 4. The final coal-air temperature is shown stored in OPVB 20.

Pulverizer Submodel Controls

As far as the pulverizer is concerned, two things must be maintained - a constant coal-air temperature and a constant total air flow rate to the pulverizer. The latter is determined from a pulverizer capacity curve. See Figure 5 for the curve for this CE RS-863 Bowl Mill. Note that the base capacity for a single mill (pulverizer) is 106,000 lbm/hr. Since there are six mills at Cliffside, at MCR each mill runs at 74,000 lbm/hr or 69.8% of its base (or maximum) capacity.

Looking at the Exhauster Air Flow versus Percent Maximum Mill Capacity curve (Figure 5), we find that at 69.8% (say 70%) the total mass flow of air is 2,520 lbm/min, or 151,200 lbm/hr per mill. Therefore, for six mills the total air flow is 907,200 lbm/hr.

Two controls are used to determine the hot air/tempering air ratio. First, the hot air to the pulverizer (WWFIXB 800) is controlled to give a coal-air temperature of 180. °F (OPVB 20). (This can be set at any desired temperature). Second, the tempering air (WWVSC 100) is varied to give a total air flow (WW 3) of 907,200 lbm/hr (from the mill capacity curves).

As previously discussed, the surface moisture in the coal was modeled by injecting a separate source of water. Here, a third control is applied to attain a specified mass fraction of water in the coal/moisture mixture (stream 10).

The details of all three controls are listed in the input file shown in Figure 4

Results

For the base case (design, MCR) the ratio of tempering air to hot air (ta/ha) supplied to the pulverizer was 2.6:1. Without actual test data with which to compare, a few other cases were run to see if the results would correspond to what one may expect in actual operation.

For the first case the surface moisture in the coal was increased to 5.3%. This resulted in a ta/ha ratio of 2.4:1. This is reasonable since a lower ratio indicates more hot air is used. And, with an increase in surface moisture, we would expect an increase in hot air flow to maintain the coal-air mixture at 180 °F.

Next, we consider the same previous case, but maintain a 2.6 ta/ha ratio and allow the coal-air temperature to float. The resulting temperature is 173.6 °F.

In the final case the coal-air temperature was lowered to 150 °F; the surface moisture was set at design (0.%). The ta/ha ratio increased to 4.2:1; a reasonable result since less hot air would be needed to maintain a lower coal-air temperature. For a summary of the results see Figure 6.

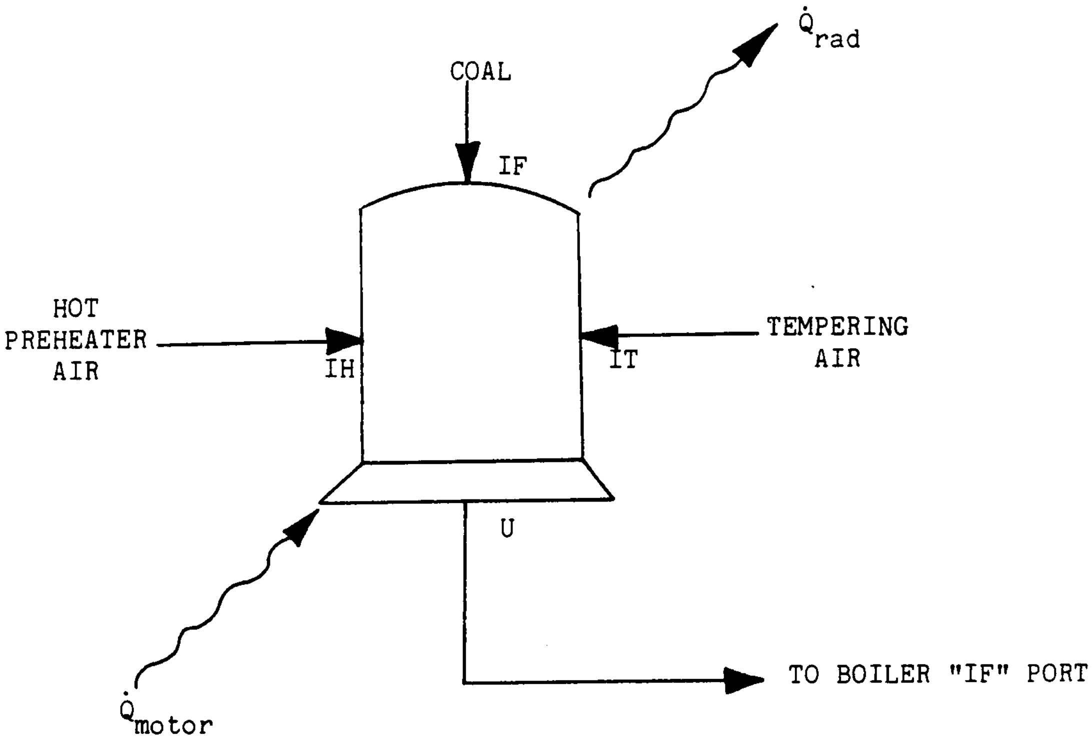
Further Applications and Suggestions

This submodel has proven useful in a larger performance-mode boiler model. With the appropriate boiler efficiency calculation options the performance effects of pulverizer operation could be accurately determined. For example, the effect on dry gas loss (DGL) due to operating with a lower coal-air temperature can be evaluated. Intuitively, a lower coal-air temperature should increase the DGL since more tempering air, which bypasses the air preheater, is used. This, in turn, results in an increased exit gas temperature from the air preheater. With a boiler model set up as mentioned, this effect can be quantified and used to recommend changes in pulverizer operation and/or modifications to coal-air temperature controls.

A further suggestion is to verify the pulverizer/boiler model by conducting tests. A specific mill test could be done to check the submodel, or a complete boiler test could be performed for a broader perspective.

Looking into the future of the PEPSE code, and possible boiler model modifications, it would be a tremendous aid to the user to have a discrete pulverizer component.

The following is what a PEPSE pulverizer component might look like along with some suggested inputs:



Inputs:

- coal-air temperature
- total primary air flow to pulverizer
- surface moisture content of coal (input via fuel card)
- $Q_{rad.}$, Q_{motor}
- flag for pulverizer-out-of-service

Summary

As a need for quantifying the tempering air flow to a pulverizer arose, an attempt was made to model more precisely the true operation of a pulverizer in a boiler system. With the failure of a direct approach to this model, due to peculiarities in the PEPSE code, an indirect approach using operations and controls was used.

The coal-air mixture temperature was calculated using PEPSE operations and was held constant (as in true boiler operation) by using PEPSE controls. Other controls were used, as well, to maintain a constant primary air flow to the pulverizer, and to control the surface moisture content of the coal.

Several cases were run where the surface moisture and coal-air temperature were varied, and the results were in line with what we would intuitively expect to happen in actual boiler operation. Further investigation will continue by verifying the pulverizer model with actual field testing.

Acknowledgements

Thanks to Martin Davidson for collaborating on the development of the model, and for editorial comments on the final paper.

References

Reference 1:
Mark's Standard Handbook for Mechanical Engineers; Baumeister, Avallone, Baumeister, Eighth Edition; McGraw-Hill, 1958

DIRECT FIRING SYSTEM

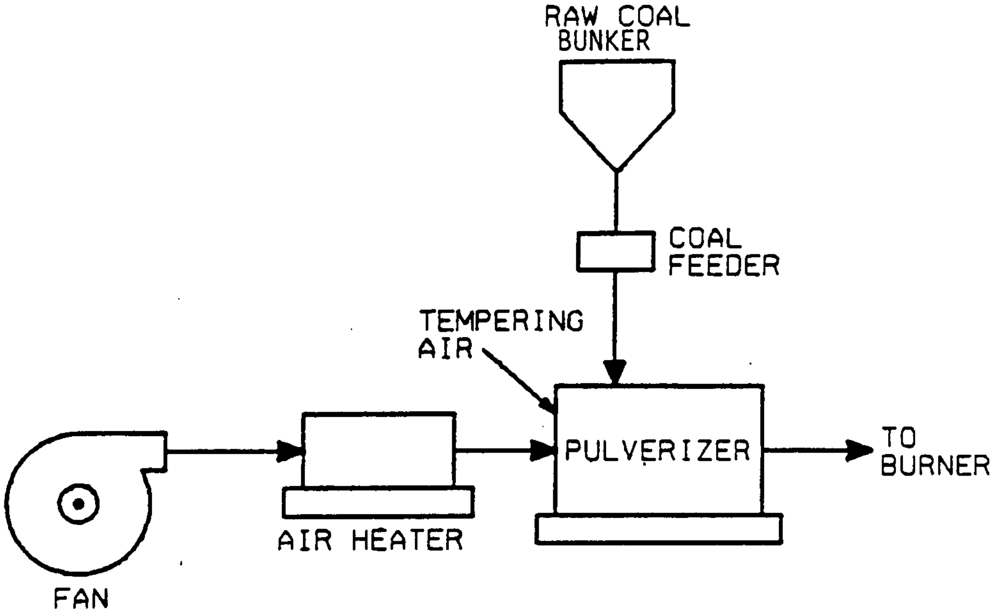
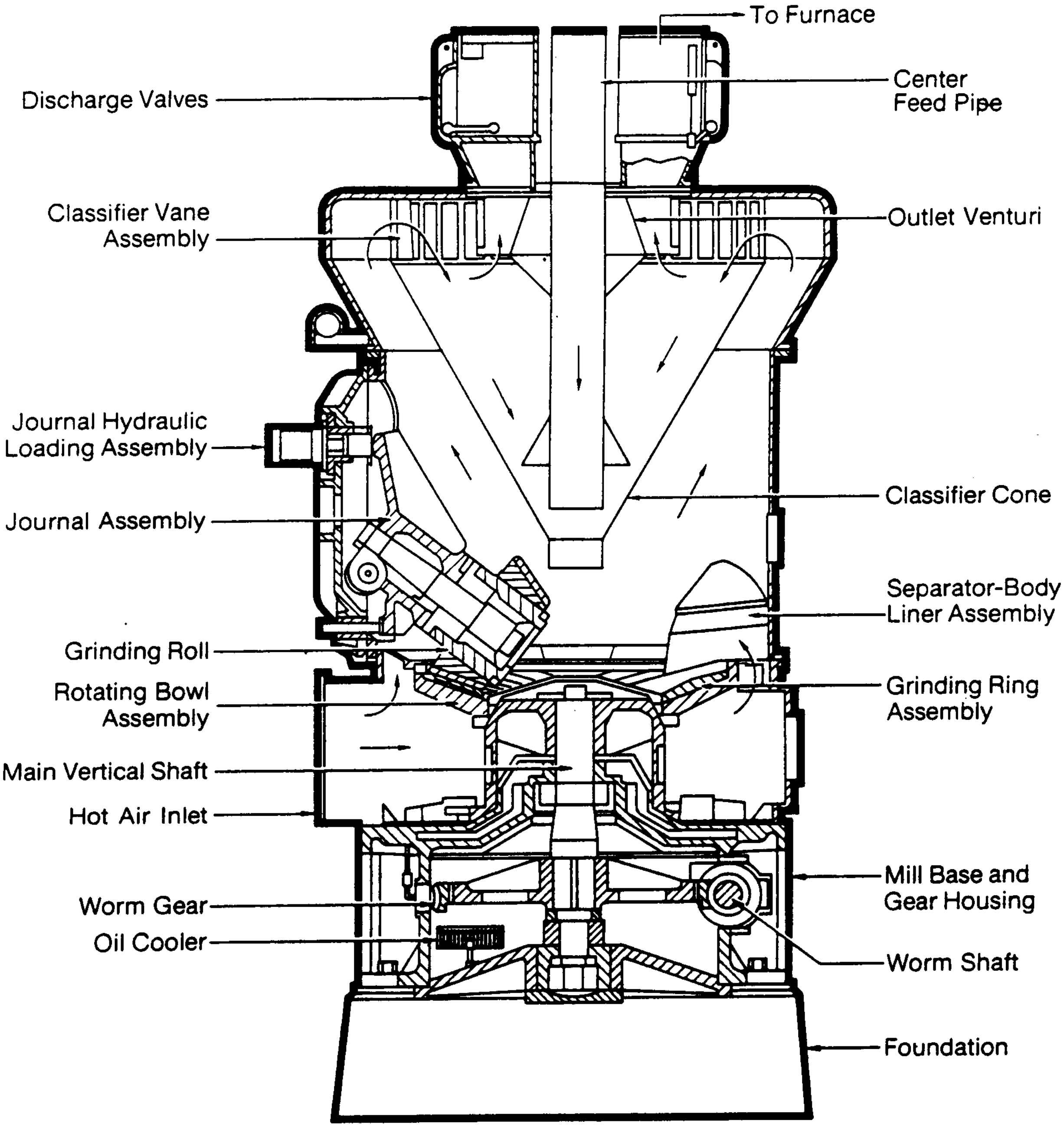


Fig. 1



C-E bowl mill, shallow bowl (RP, RPS, and RS) type

Fig. 2

PULVERIZER SUBMODEL

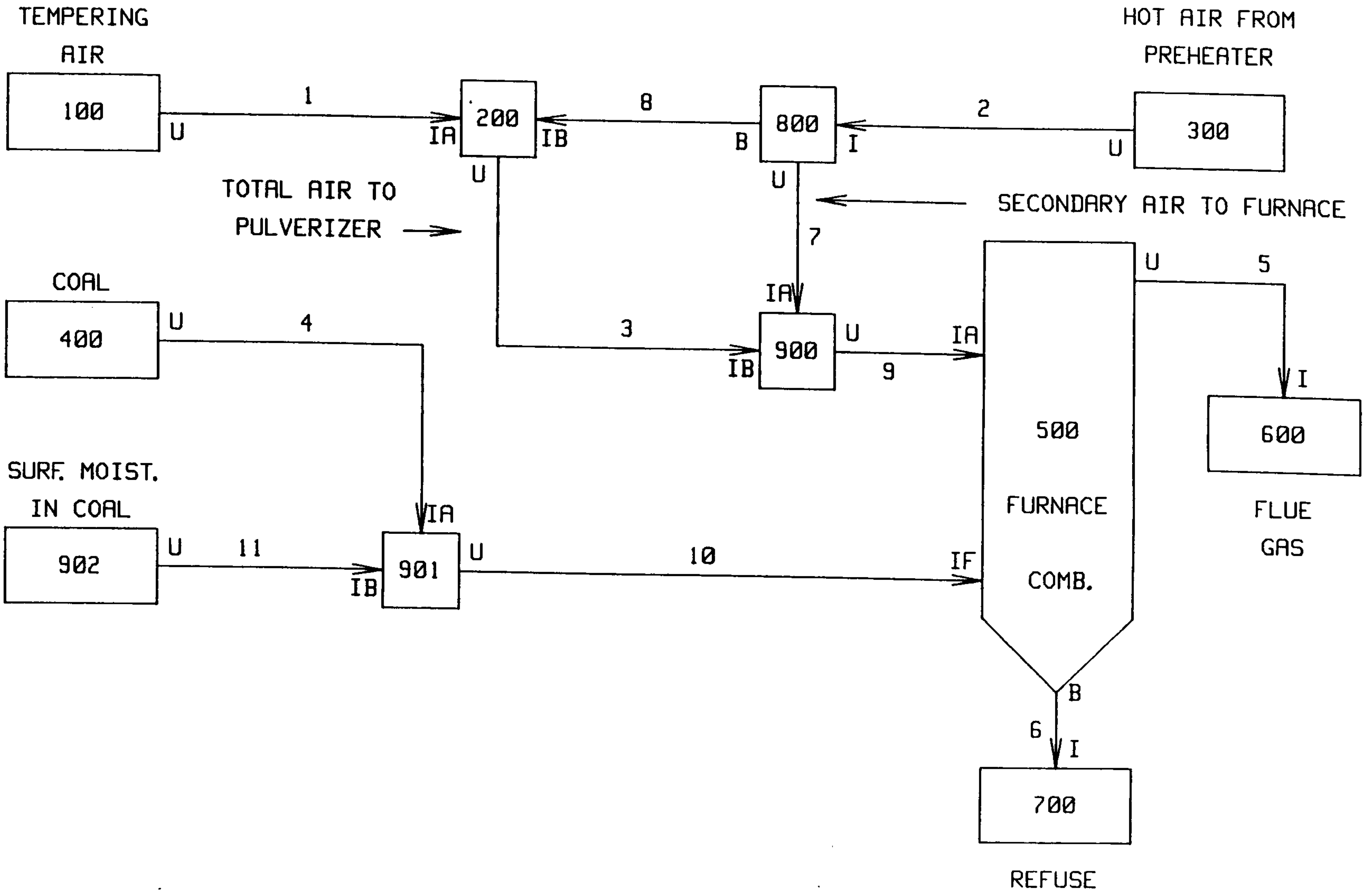


Fig. 3

PEPSE INPUT FOR PULVERIZER SUBMODEL

Fig. 4

```
=SUBPLVA
010200 0
012000 100
500010 100 U 200 IA
500020 300 U 800 I
500030 200 U 900 IB
500040 400 U 901 IA
500050 500 U 600 I
500060 500 B 700 I
500070 300 U 900 IA
500080 800 B 200 IB
500090 900 U 500 IA
500100 901 U 500 IF
500110 902 U 901 IB
*TEMPERING AIR
701000 33 80. 14.7 642114.
701003 AIR -.013
702000 50
*HOT AIR FROM PREHEATER
703000 31 631. 14.7 265086.
703003 AIR -.013
*COAL SOURCE
704000 31 80. 14.7 444000.
704003 FUEL 12000. SSVL 0. C .72 H2 .0465 O2 .0035
704004 N2 .012 S .008 ASH .16 H2O .05
*FURNACE/COMBUSTOR
705000 70 1 3 300 .20
706000 32
707000 30
708000 61 0. 265086.
709000 50
709010 50
*SURFACE MOISTURE IN COAL
709020 31 80. 14.7 0.
*OPERATIONS FOR COAL-AIR TEMP. CALCULATIONS
870010 .3                                        * CP COAL
880020 PP      8    GPTC TT     8   OPVB 2   * CP H.AIR
880030 PP      1    GPTC TT     1   OPVB 3   * CP T.AIR
880040 WWVSC  400   MUL  OPVB   1   OPVB 4
880050 WWFIXB 800   MUL  OPVB   2   OPVB 5
880060 WWVSC  100   MUL  OPVB   3   OPVB 6
880070 TTVSC  400   MUL  OPVB   4   OPVB 7
880080 TTVSC  300   MUL  OPVB   5   OPVB 8
880090 TTVSC  100   MUL  OPVB   6   OPVB 9
880100 OPVB    7    ADD  OPVB   8   OPVB 10
880110 OPVB   10    ADD  OPVB   9   OPVB 11
880120 OPVB    4    ADD  OPVB   5   OPVB 12
880130 OPVB   12    ADD  OPVB   6   OPVB 13
880140 OPVB   11    DIV  OPVB   13  OPVB 14  *COAL-AIR TEMP.
880150 PP     11    GPTC TT     11  OPVB 15  *CP H2O
880160 OPVB   15    MUL  WWVSC 902  OPVB 16
880170 OPVB   16    MUL  TTVSC 902  OPVB 17
880180 OPVB   11    ADD  OPVB   17  OPVB 18
880190 OPVB   13    ADD  OPVB   16  OPVB 19
880200 OPVB   18    DIV  OPVB   19  OPVB 20  *COAL-AIR TEMP.(W/MOIST COAL)
* CONTROLS:
*HOT AIR TO GET COAL-AIR TEMP.:
840100 WWFIXB 800 180. .0001 1.0 OPVB 20
840109 100000. 500000.
*TEMPERING AIR TO GET MASS FLOW OF AIR TO PULV.:
840200 WWVSC 100 907200. .000001 1.0 WW 3
*H2O ADDED TO COAL TO GET DESIRED  % MOISTURE:
*840300 WWVSC 902 .10 .0001 1.0 H2OS 10
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CE Pulverizer Curve - Bowl Mill RS-863

Base Capacity = 106,000 lbm/hr.

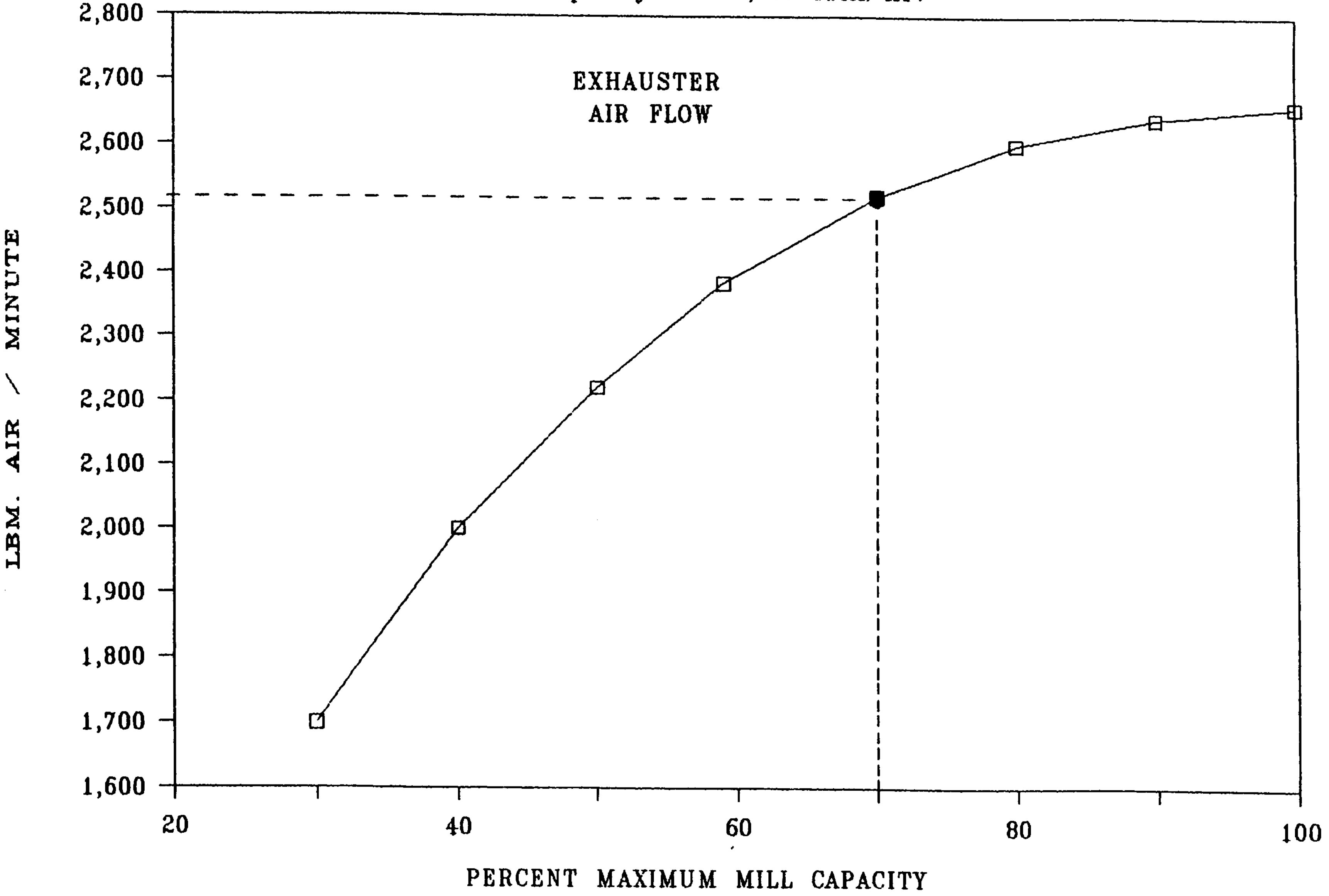


Fig. 5

RESULTS

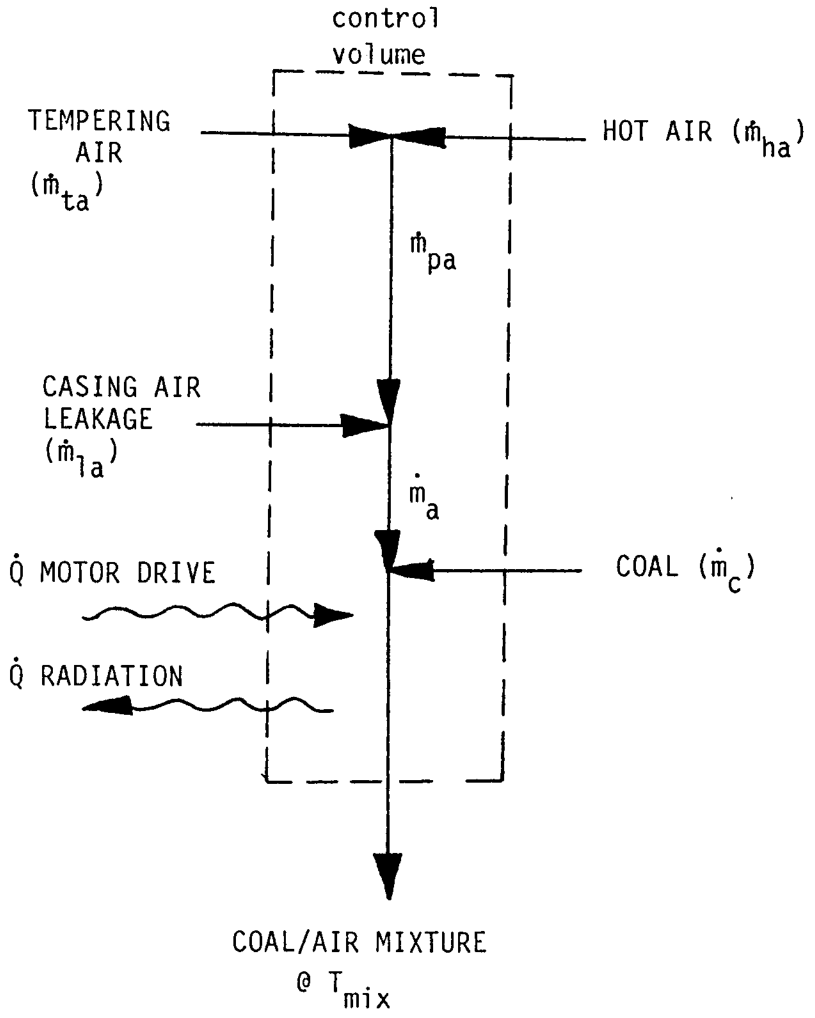
PEPSE Pulverizer Submodel	T_{mix} (°F)	$\dot{M}_{ha}$ (lbm/hr)	$\dot{M}_{ta}$ (lbm/hr)	ta/ha (mass) ratio	sm* (%)
BASE CASE: (design) MCR	180.	252,249.	654,951.	2.60	0.
CASE 1: (incr. moist. in coal, constant T_{mix})	180.	269,719.	637,481.	2.36	5.3
CASE 2: (incr. moist. in coal, constant tempering air flow)	173.6	252,249.	654,951.	2.60	5.3
CASE 3: (lower T_{mix})	150.	176,126.	731,074.	4.15	0.

*not including inherent moisture

Fig. 6

ADDENDUM TO PEPSE PULVERIZER SUBMODEL

Upon closer examination of the pulverizer submodel calculations, it was found that the equation for the coal-air temperature (T_{mix}) did not include the effect of the latent heat of vaporization for the moisture in the fuel. This addendum contains a corrected T_{mix} equation which is derived from an energy balance around the pulverizer. The heat gain from the drive motor and heat loss from radiation are also accounted for in the new equation (in the original submodel these two factors were assumed to cancel each other). Casing air inleakage is also modeled to more realistically represent actual operation. The sensible heat loss due to mill spillage is neglected. A modified PEPSE schematic is shown in Fig. 1. The heat balance diagram is shown below:



GIVEN CONDITIONS AND ASSUMPTIONS

• Atmospheric Pressure	= 14.7 psia
• Hot Air (exiting preheater) Temperature	= 631. °F
• Tempering Air Temperature	= 80. °F
• Ambient Coal Temperature	= 80. °F
• Maximum Coal Air Temperature	= 180. °F
• Air Humidity Ratio	= $.013 \frac{\text{lbm } H_2O}{\text{lbm dry air}}$
• Coal Mass Flow Rate	= 444,000 lbm/hr.
• Excess Air Leaving Furnace	= 20%
• Coal Heating Value	= 12,000 Btu/lbm
• Ultimate Analysis of Coal:	

C	72.0%
H_2	4.65%
O_2	.35%
N_2	1.2%
S	.8%
Ash	16.0%
H_2O	5.0%

* • Residual Moisture in Pulverized Coal	= 1.5%
* • Radiation Loss from Pulverizer	= 5% of heat input
* • Heat Gain from Drive Motor	= 13 Btu/lbm coal
* • Casing Air Inleakage	= .20 lbm air/lbm coal

*These values are obtained from the pulverizer vendor curves. See Fig. 3.

NOMENCLATURE:

$\dot{m}_{ta}$ = mass flow rate of tempering air (lbm/hr)
$\dot{m}_{ha}$ = mass flow rate of hot air (lbm/hr)
$\dot{m}_{pa}$ = mass flow rate of primary air (lbm/hr)
$\dot{m}_{la}$ = mass flow rate of leakage air (lbm/hr)
$\dot{m}_{a}$ = mass flow rate of total air (lbm/hr)
$\dot{m}_{c}$ = mass flow rate of coal air (lbm/hr)

T_{ta} = temperature of tempering air (°F)
T_{ha} = temperature of hot air (°F)
T_{pa} = temperature of primary air (°F)
T_{la} = temperature of leakage air (°F)
T_{a} = temperature of total air (°F)
T_{c} = temperature of ambient coal (°F)
T_{mix} = temperature of coal/air mixture (°F)
T_{w} = temperature of ambient moisture in coal (°F)

Cp_{ta} = Specific heat of tempering air (Btu/lbm °F)
Cp_{ha} = Specific heat of hot air (Btu/lbm°F)
Cp_{pa} = Specific heat of primary air (Btu/lbm °F)
Cp_{la} = Specific heat of leakage air (Btu/lbm °F)
Cp_{a} = Specific heat of total air (Btu/lbm °F)
Cp_{c} = Specific heat of coal (Btu/lbm °F)

H_1 = Heat input of total air (Btu/hr)
H_2 = Heat input from drive motor (Btu/hr)
H_3 = Heat loss from radiation (Btu/hr)
H_4 = Heat to raise dry coal from ambient temp. to mill outlet temp. (Btu/hr)
H_5 = Heat to evaporate moisture in coal and raise to mill outlet temp. (Btu/hr)
H_6 = Heat to raise residual moisture in coal to mill outlet temp. (Btu/hr)

M = Moisture in raw coal (%/100)
R = Residual moisture in pulverized coal (%/100)
HGTM = Enthalpy of saturated steam at mill outlet temp. (Btu/lbm)
HFTW = Enthalpy of saturated water at ambient coal temp. (Btu/lbm)

CALCULATIONS

An energy balance around the pulverizer control volume yields:

$$H_1 + H_2 = H_3 + H_4 + H_5 + H_6$$

Looking at the individual heat gains/losses:

$H_1 = \dot{m}_a \, Cp_a(T_a - T_{mix})$

$H_2 = 13 \, \dot{m}_c$

$H_3 = .05(\dot{m}_a Cp_a(T_a - T_{mix}) + 13 \, \dot{m}_c)$

(NOTE: H_2 and H_3 are obtained from manufacturer's data)

$H_4 = \dot{m}_c \, Cp_c \, (1-M)(T_{mix} - T_c)$

$H_5 = \dot{m}_c[(M-R)/(1-R)](HGTM - HFTW)$

$H_6 = \dot{m}_c[1-(M-R)] \, (R)(T_{mix} - T_w)$

Substituting these terms into the energy balance equation, expanding the equation, and solving for T_{mix} yields the following expression for T_{mix}:

$$T_{mix} = \frac{\begin{array}{c}[-.95\dot{m}_a Cp_a T_a - 12.35\dot{m}_c - \dot{m}_c Cp_c T_c + \dot{m}_c Cp_c M T_c \\ + \dot{m}_c[(M-R)/(1-R)](HGTM-HFTW) - \dot{m}_c R T_w + \dot{m}_c R M T_w - \dot{m}_c R^2 T_w]\end{array}}{-.95\dot{m}_a Cp_a - \dot{m}_c Cp_c + \dot{m}_c Cp_c M - \dot{m}_c R + \dot{m}_c R M - \dot{m}_c R^2}$$

PEPSE OPERATIONS AND CONTROLS

As in the original submodel, operations are written to calculate a coal-air temperature for each iteration. These operations are shown in the input data for the model (See Fig. 2). The convergence scheme is the same as the original model; specifically, the hot air flow is varied to get a coal-air temperature of 180 °F, and the tempering air flow is controlled to yield a total air flow of 907,200 lbm/hr. (This flow is obtained by the method shown in the original paper). Note that the control convergence tolerance on control set 1 had to be loosened to $5.56(10)^3$ for it to converge.

RESULTS

For the given inputs and assumptions the results were as follows:

- Tempering Air Flow = 464,976. lbm/hr
- Hot Air Flow = 353,424. lbm/hr
- Primary Air Temperature = 322.3 °F

SUMMARY

This addendum to the paper, A PEPSE Pulverizer Submodel, properly accounts for the heat transfer due to evaporation of the moisture in the fuel, radiation loss, and heat gain from the drive motor. This is accomplished through a detailed energy balance around the pulverizer.

These changes result in a hot air to tempering air ratio of .76 for the given conditions and assumptions in the model. The resulting primary air temperature (temperature of the air delivered to the pulverizer inlet) is 322.3 °F.

PULVERIZER SUBMODEL

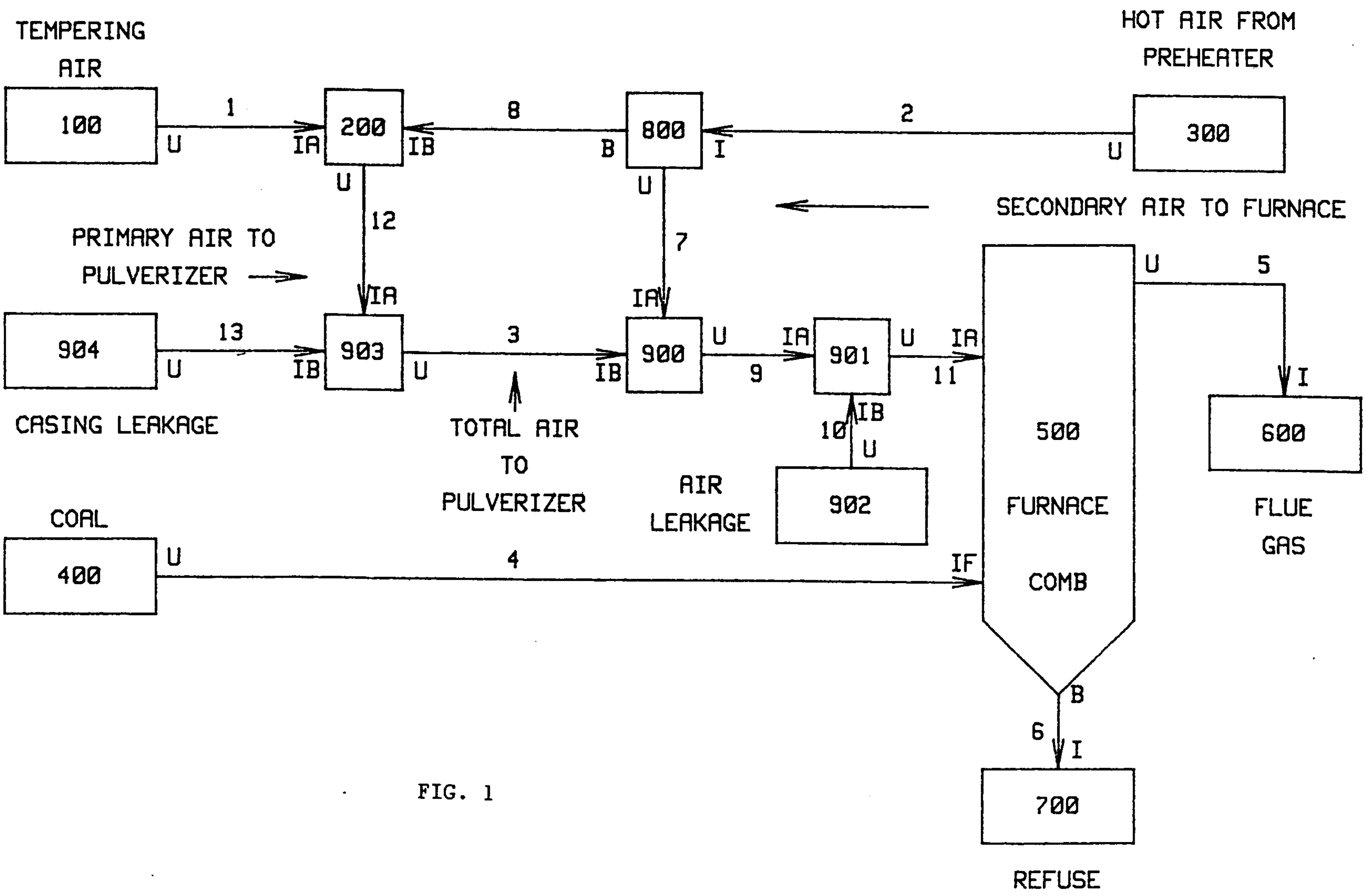


FIG. 1

```
=SUBPLVA : FOR CLIFFSIDE 5
*REV. 11-17-87 GWE: ADDENDUM TO SUBMODEL
010200 0
012000 100
*GEOMETRY
500010 100 U 200 IA
500020 300 U 800 I
500030 903 U 900 IB
500040 400 U 500 IF
500050 500 U 600 I
500060 500 B 700 I
500070 800 U 900 IA
500080 800 B 200 IB
500090 900 U 901 IA
500100 902 U 901 IB
500110 901 U 500 IA
500120 200 U 903 IA
500130 904 U 903 IB
*TEMPERING AIR
701000 33 80. 14.7 472229.6
701003 AIR -.013
702000 50   *MIX TEMP. AND HOT AIR
*HOT AIR FROM PREHEATER
703000 31 631. 14.7 4140000.
703003 AIR -.013
*COAL SOURCE
704000 31 80. 14.7 444000.
704003 FUEL 12000. SSVL 0. C .72 H2 .0465 02 .0035
704004 N2 .012 S .008 ASH .16 H20 .05
*FURNACE/COMBUSTOR
705000 70 1 3 300 .20
706000 32                 *FLUE GAS SINK
707000 30                 *REFUSE SINK
708000 61 0. 346170.4     *HOT AIR TO PULV. SPLITTER
709000 50                 *AIR MIXER
709010 50                 *BOILER AIR INLEAKAGE
709030 50                 *CASING AIR INLEAKAGE
* AIR INLEAKAGE-BOILER
709020 31 80. 14.7 145000.
709023 AIR -.013
* CASING LEAKAGE
709040 31 80. 14.7 88300.
709043 AIR -.013
* OPERATIONS FOR TMIX:
870010 .325        * CP COAL
870020 .015        * R: MOIST. LEAVING
870030 180.        * COAL/AIR TEMP. MIX
870040 907200.     * PRIM. AIR FLOW
870050 -.95        * CONST.
870060 -12.35      * CONST.
870070 0.          * CONST.
870550 1.          * CONST.
880010 PP       1  GPTC TT       1 OPVB 8     * CPTA,CPLA
880020 PP       8  GPTC TT       8 OPVB 9     * CPHA
880030 OPVB     7  SAP  OPVB     3 OPVB 10    * PSAT @ TMIX
880040 OPVB     7  PHG  OPVB    10 OPVB 11    * HGTM
880050 OPVB     7  SAP  TTVSC 400 OPVB 12     * PSAT @ TC
880060 OPVB     7  PHF  OPVB    12 OPVB 13    * HFTW
880070 WWVSC 100   MUL  OPVB     8 OPVB 46    * MTA(CPTA)
880080 OPVB    46  MUL  TTVSC 100 OPVB 47     * MTA(CPTA)(TTA)
880090 WWFIXB 800 MUL  OPVB     9 OPVB 48    * MHA(CPHA)
880100 OPVB    48  MUL  TT       8 OPVB 49    * MHA(CPHA)(THA)
880110 WWVSC 904   MUL  OPVB     8 OPVB 50    * MLA(CPLA)
880120 OPVB    50  MUL  TTVSC 904 OPVB 51     * MLA(CPLA)(TLA)
880130 OPVB    47  ADD  OPVB    49 OPVB 52    * 47+49
880140 OPVB    52  ADD  OPVB    51 OPVB 53    * 52+51
880150 OPVB    53  DIV  TT       3 OPVB 54    * MA(CPA)
880160 OPVB     5  MUL  OPVB    54 OPVB 14    * -.95MA(CPA)
880170 OPVB    14  MUL  TT       3 OPVB 15    * -.95MA(CPA)(TA)
880180 OPVB     6  MUL  WWVSC 400 OPVB 16     * -12.35MC
880190 WWVSC 400   MUL  OPVB     1 OPVB 17    * MC(CPC)
880200 OPVB    17  MUL  TTVSC 400 OPVB 18     * MC(CPC)(TC)
880210 OPVB    18  MUL  H2OS     4 OPVB 19    * MC(CPC)(TC)(M)
880220 H2OS     4  SUB  OPVB     2 OPVB 20    * M-R
880230 OPVB    55  SUB  OPVB     2 OPVB 21    * 1-R
880240 OPVB    20  DIV  OPVB    21 OPVB 22    * (M-R)/(1-R)
880250 WWVSC 400   MUL  OPVB    22 OPVB 23    * MC(M-R)/(1-R)
880260 OPVB    11  SUB  OPVB    13 OPVB 24    * HGTM-HFTW
```

FIG. 2

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880270 OPVB   23  MUL  OPVB   24 OPVB 25   * MC((M-R)/(1-R))(HGTM-HFTW
880280 OPVB   17  MUL  H2OS    4 OPVB 26   * MC(CPC)(M)
880290 WWVSC 400  MUL  OPVB    2 OPVB 27   * MC(R)
880300 OPVB   27  MUL  H2OS    4 OPVB 28   * MC(R)(M)
880310 OPVB   27  MUL  OPVB    2 OPVB 29   * MC(R)(R)
880320 OPVB   27  MUL  TTVSC 400 OPVB 30   * MC(R)(TW)
880330 OPVB   30  MUL  H2OS    4 OPVB 31   * MC(R)(TW)(M)
880340 OPVB   29  MUL  TTVSC 400 OPVB 32   * MC(R)(R)(TW)
880350 OPVB   15  ADD  OPVB   16 OPVB 33   * 15+16
880360 OPVB   33  SUB  OPVB   18 OPVB 34   * 33-18
880370 OPVB   34  ADD  OPVB   19 OPVB 35   * 34+19
880380 OPVB   35  ADD  OPVB   25 OPVB 36   * 35+25
880390 OPVB   36  SUB  OPVB   30 OPVB 37   * 36-30
880400 OPVB   37  ADD  OPVB   31 OPVB 38   * 37+31
880410 OPVB   38  SUB  OPVB   32 OPVB 39   * 38-32
880420 OPVB   14  SUB  OPVB   17 OPVB 40   * 14-17
880430 OPVB   40  ADD  OPVB   26 OPVB 41   * 40+26
880440 OPVB   41  SUB  OPVB   27 OPVB 42   * 41-27
880450 OPVB   42  ADD  OPVB   28 OPVB 43   * 42+28
880460 OPVB   43  SUB  OPVB   29 OPVB 44   * 43-29
880470 OPVB   39  DIV  OPVB   44 OPVB 45   * 39/44 = TMIX
*HOT AIR TO GET COAL-AIR TEMP.:
840100 WWFIXB 800 180. 5.56E-3 1.0 OPVB 45
840109 1000. 1000000.
*TEMPERING AIR TO GET MASS FLOW OF AIR TO PULV.:
840200 WWVSC 100 818400. .000001 1.0 WW 12
840209 1000. 1000000.
*SPECIAL OUTPUT PROCESSOR
890010 'COAL/AIR TEMP. (F)'
890011 OPVB 45
890020 'PRIM. AIR FLOW (LBM/HR)'
890021 WW 12
890030 'PRIM. AIR TEMP.'
890031 TT 12
890040 'TEMP. AIR FLOW (LBM/HR)'
890041 WW 1
890050 'HOT AIR FLOW (LBM/HR)'
890051 WW 8
890060 "CASING AIR LEAK. (LBM/HR)"
890061 WW 13
890070 'COAL FLOW (LBM/HR)'
890071 WWVSC 400
890080 'TOT. MOIST.(M: FRACT)'
890081 H2OS 4
890090 'RES. MOIST (R: FRACT)'
890091 OPVB 2
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FIG. 2
(Cont.)

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                SPECIAL OUTPUT TABLE OF SPECIFIED VARIABLES

                 DESCRIPTION                         VARIABLE (ID)         VALUE

'COAL/AIR        TEMP.    (F)'                       OPVB   (  45)      1.793297E+02
'PRIM.   AIR     FLOW     (LBM/HR)'                  WW     (  12)      8.184000E+05
'PRIM.   AIR     TEMP.'                              TT     (  12)      3.222830E+02
'TEMP.   AIR     FLOW     (LBM/HR)'                  WW     (   1)      4.649761E+05
'HOT     AIR     FLOW     (LBM/HR)'                  WW     (   8)      3.534239E+05
CASING AIR LEAK. (LBM/HR)                            WW     (  13)      8.880000E+04
'COAL    FLOW     (LBM/HR)'                          WWVSC  ( 400)      4.440000E+05
'TOT.    MOIST.(M:        FRACT)'                    H2OS   (   4)      5.000000E-02
'RES.    MOIST    (R:     FRACT)'                    OPVB   (   2)      1.500000E-02
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MILL AIR TEMPERATURES

BASED ON MILL LEAKAGE OF 0.20 LBS. AIR/LB COAL, MILL DRIVE HEAT OF 13 BTU/LB COAL AND A 5% RADIATION LOSS

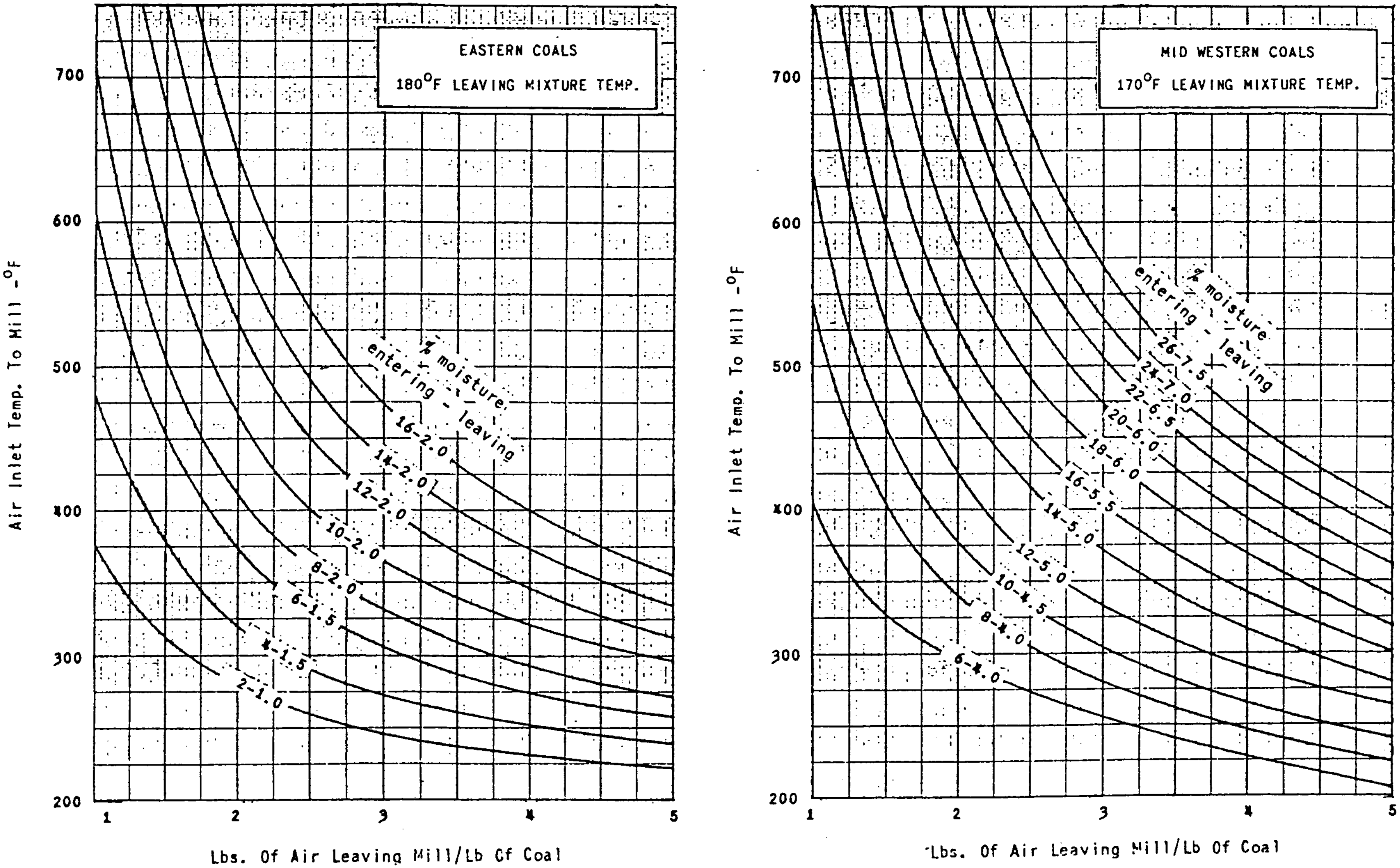

FIG. 3