NOTICE

**CERTAIN DATA
CONTAINED IN THIS
DOCUMENT MAY BE
DIFFICULT TO READ
IN MICROFICHE
PRODUCTS.**

AERATED ATOMIZATION OF COAL-WATER SLURRY FUELS

DOE/PC/79913--T10

DE91 001312

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

by: H. N. Buckner,
P. E. Sojka,
and A. H. Lefebvre,

contract number: DE-FG22-87PC79913

for: DOE/PETC
PM-20, MS 922-208

contract monitor: Mr. Anthony Mayne

APRIL 1989

Department of Mechanical Engineering
Purdue University

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

ANALYSIS

In order to obtain a more thorough understanding of the physical phenomena involved when using aerated atomization, a mathematical study was undertaken. Previous expressions relating mean drop size to fluid physical properties and nozzle operating conditions have been developed from considerations of liquid sheet and jet instability. As such, they can not be applied to the results of this study since aerated atomization produces neither a sheet nor a jet. Instead, an expression was developed from energy and momentum considerations. It is based on the one-dimensional flow of a two-phase fluid with the liquid phase being of primary interest. The gas phase is analyzed only as source terms in the liquid momentum and energy equations.

Consider the region of space which begins at the nozzle exit plane and extends to the line at which spray measurements were made. Assume that the flow is one-dimensional, steady, isothermal, with negligible evaporation, and that entrainment is second order. Neglect of evaporation is justified by the low volatility of the liquids employed here, while entrainment can be ignored since it is assumed that the spray and air expand along the boundary of the control volume. As a result of these assumptions, the energy necessary to increase the surface area of the liquid as it forms droplets and to accelerate the droplets after they are formed must be provided by the initial kinetic energy of the liquid, the decrease in kinetic energy of the air, the

initial surface energy due to macro-bubbles, and the potential for boundary work associated with the macro-bubbles. The expression relating these quantities is written as:

$$\frac{\dot{m}_a \cdot V_a^2}{2} + \frac{\dot{m}_l \cdot V_l^2}{2} + \dot{m}_a \cdot RT \cdot \ln\left(\frac{P_a}{P_{amb}}\right) + SE_b = \frac{(\dot{m}_a + \dot{m}_l)}{2} \cdot V^2 + SE_d$$

It is reasonable to assume that the velocities of the droplets and air are equal at the point where droplet size measurements are made. This velocity can be calculated by applying conservation of momentum and assuming drag forces, due primarily to entrainment, are small:

$$V = \frac{m_a V_a + m_l V_l}{m_{tot}}$$

The droplet surface energy term can be rewritten in terms of the droplet SMD by relating the liquid mass to the number, mass density and size of drops in the spray:

$$SE_d = \sum, n, \pi d^2, \sigma = \frac{6 \cdot \sigma}{\rho_l SMD_d}$$

The bubble surface energy term can be rewritten in terms of the bubble SMD by first multiplying and dividing by the air mass flow rate and then relating the mass of air to the number, density and size of bubbles. Application of the ideal gas law then results in:

$$SE_b = \sum, n, \pi d^2, \sigma = \frac{6 \cdot \sigma}{\rho_a SMD_b}$$

Equation (2) is substituted into Equation (1) and the result divided by the liquid mass flow rate. It should be noted that not all the available energy is utilized to increase the droplet surface area. As a result, two efficiency factors are incorporated in Equation (5). The first, β , describes the fraction of bubble potential energy available to decrease SMD. The second, α , describes the efficiency of energy transfer from kinetic and bubble surface energy to droplet surface energy.

$$SMD = \frac{6 \cdot \sigma}{\rho_l \cdot ALR} \cdot \frac{\alpha}{\frac{(v_a - v_l)^2}{(1 + ALR)} + RT \cdot \left[\beta \cdot \ln \left(\frac{p_a}{p_s} \right) + \frac{6 \cdot \sigma}{p_s \cdot SMD_b} \right]}$$

The analysis predicts the surface energy of the bubbles to be negligible; therefore, the model exhibits the dependence of SMD on potential and kinetic energy of the spray. Figure 1 presents measured SMD versus calculated SMD. This figure represents conditions where β is held constant and α is varied according to the polynomial $\alpha = C_1 + C_2 \cdot ALR + C_3 \cdot ALR^2$. The efficiency, β , was found to be very low, on the order of .001, and α was determined to be in the range of 0.1 to 1.0. It is evident that the analysis shows good agreement with actual data.

By dividing the kinetic energy terms in the expression by α , the actual contribution of these energy terms can be determined. Figure 2 shows the contribution of the kinetic energy versus SMD. Notice that the kinetic energy contribution decreases with increasing SMD. This phenomena is a result of the reduction of the void fraction as

the ALR is reduced. This reduction causes the velocity difference between the bubbles and the fluid to drop resulting in a reduced kinetic energy difference between the air and the liquid.

The actual contribution of the potential energy is expressed in Figure 2. The analysis shows the potential energy contribution increases with SMD. As the ALR becomes smaller, a larger amount of liquid comes into contact with the air contained in the bubbles; therefore, the energy transport between the air and the liquid becomes more efficient.

The relative contribution of the two energy terms was compared and is exhibited in Figure 3. The magnitude of the potential energy term dominates the break up process over most of the data range. Eventually, the potential energy contribution is exceeded by the kinetic energy contribution due to the significant decrease in the efficiency of the potential energy contribution.

PHOTOGRAPHS

In order to explain the low efficiency of energy transfer exhibited by the potential energy, an investigation of the flow structure at the nozzle exit was performed. Schlieren photographs were made of the flow at the nozzle exit as functions of ALR and liquid viscosity. At each data point, the nozzle was first operated with air alone to illustrate the air flow structure in the absence of liquid. It was

then operated with liquid flow at the same air flow condition and another picture was taken. Representative photographs are shown in Figures 5-12.

The air only photographs show that, in all cases, the air was supersonic downstream of the nozzle exit, as demonstrated by the shock diamonds. Upon adding liquid, shock diamonds were still visible in the high ALR region, but as ALR was reduced the shocks disappeared. Obviously, the air that was supersonic had not impacted any liquid. If it had, the energy needed to achieve supersonic conditions would have been transferred to the liquid and supersonic flow would not have been possible. This demonstrates that large amounts of energy are wasted due to a lack of contact between the air and liquid and explains the low efficiency of the potential energy that is exhibited in the analysis above.

FUTURE WORK

The analysis presented above provides significant insight into the physical properties of the spray. In order to improve the analysis, the efficiency parameters and the non-isentropic expansion of the air will be addressed. For instance, the efficiency factor β currently includes the shock losses exhibited in the schlieren photographs. By assuming a non-isentropic expansion of the air, the potential energy contribution will decrease, reflecting the energy unavailable due to shock losses and β will more accurately represent the efficiency of this energy transfer process.

In addition to developing a more accurate model, spray data will be taken using non-Newtonian mixtures. This data will include SMD measurements and photographs of the internal nozzle flow and spray development.

CONCLUSION

The preliminary mathematical analysis of the spray showed that the macro-bubble energy potential and the velocity difference between the air and the liquid in the two-phase flow are the significant contributions to the spray break-up. It also revealed the relative contribution of each energy source to the break-up. Associated with these energy sources are two efficiencies, α and β , that provide a measure of the efficiency associated with this atomization process. The efficiency associated with macro-bubble expansion, β , is found to be very low.

Schlieren photographs taken of the flow downstream of the nozzle exit indicate a substantial portion of the available energy is dissipated in a series of shock fronts emanating from the nozzle. The existence of these shocks prove that large losses result from the lack of contact between the air and the liquid.

Work will continue on the analysis with attention focused on the efficiency factors. Data will also be taken using non-Newtonian liquids.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5: Air flow 1.194 g/s

Figure 6: ALR = 0.0454

Figure 7: Air flow 1.791 g/s

Figure 8: ALR = 0.0861

Figure 9: Air flow 2.656 g/s

Figure 10: ALR = 0.1736

Figure 11: Air flow 3.522 g/s

Figure 12: ALR = 0.3354

-END-

DATE FILMED

11 / 20 / 90