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**INVESTIGATION OF HIGH VELOCITY SEPARATOR FOR PARTICLE
REMOVAL IN COAL GASIFICATION PLANTS**

Phase 2 Report

**By
Hans D. Linhardt**

January 15, 1980

Work Performed Under Contract No. EF-77-C-01-2709

**Linhardt & Associates, Inc.
Newport Beach, California**

U. S. DEPARTMENT OF ENERGY

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by

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FOREWARD

This report was prepared by Linhardt & Associates, Inc., under Contract EF-77-C-01-2709 for the Department of Energy, Division of Coal Conversion and Utilization. Mr. Alan I. Berusch served as Project Manager for the Department of Energy, Dr. H. D. Linhardt as the Principal Investigator and Mr. J. H. Beveridge as Project Manager. The contributions of Mr. C. G. Boone and Mr. G. B. Bosco deserve recognition. The valuable support of Dr. F. E. Marble, Professor of Jet Propulsion, Mechanical Engineering at the California Institute of Technology, is appreciated.

ABSTRACT

This report summarizes the results of Phase II of the High Velocity Particle Separator Program performed under Contract EF-77-C-01-2709. The program consisted of two phases. The results of Phase I, concerned with the conceptual design and feasibility study of a high velocity wedge separator has been summarized in Reference (1). The separator under investigation has the potential to reduce equipment size and cost of high temperature and pressurized particulate removal equipment for coal derived gases.

Phase II has been directed toward testing and detailed conceptual design of an element suitable for a commercial scale high temperature, high pressure particle separator (HTPS). Concurrently, Phase IA has been conducted, which utilized the ambient analog method (AAM) for aerodynamic and collection performance investigation of each HTPS configuration prior and during hot testing. This report summarizes the results of Phase IA and II.

Phase IA is basically a continuation of Phase I with the objective to verify theory and develop improved geometries prior to hot testing. The AAM effort established correlation of theoretical analysis and experiment for HTPS pressure drop, purge flow ratio and collection efficiency potential.

Phase II consisted of five tasks. Task I defined the initial test conditions to be the contract design point of 1800°F and 350 psia. It was learned during the AAM work that any testing at temperatures and pressures less than design would not add any significant new information. Therefore Task I selected the final contract conditions as design conditions. The final design and fabrication of the single curved channel separator, HTPS-1, and the dual channel HTPS-2 was accomplished during Task II. While Task III was initially directed toward low and moderate pressures, this effort was eliminated in lieu of additional AAM

work and testing immediately and/or concurrently with the hot testing. The 1800°F, 350 psia testing was conducted during Task IV, which represents the main high temperature testing with coal derived particulates in the 2-10 micron range. Based upon the results of Phase IA and II, and the methodology developed under Phase I and expanded and refined during the Phase II effort, the detailed conceptual design was prepared for a potential commercial application during Task V. Whereby Phase I has provided the theoretical foundation of how to separate coal derived particulates in the size range of 2-10 micrometers in diameter, Phase IA and Phase II have demonstrated efficient particle collection with acceptable pressure drop. These results were obtained under ambient and high temperature - high pressure simulated gasifier conditions. In view of these encouraging results, it is reasonable to apply the developed technology toward future hot gas particulate cleanup requirements.

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1.0 INTRODUCTION

The commercialization of large scale coal gasification plants hinges to a large degree upon the high temperature clean up of particulate and chemical trace vapor effluents. The present project is directed toward hot gas particulate clean up of pressurized gasifiers at a temperature of 1800°F. The project goal is to develop a high temperature hot gas particle separator, which operates at high collection efficiency over a particle range from 2-10 micron diameter and exhibits reasonable aerodynamic performance.

Since low temperature approaches are not applicable and multi-stage cyclones have been found ineffective for the small particle size range, innovative aerodynamic approaches have been investigated, which, for example, make use of shock structures and appropriate turning sections for high performance particle separation. While the initial theoretical and experimental investigations dealt with the high velocity wedge separator, the main effort of Phase II and IA have been directed toward reduced Mach number flow regimes in order to reduce the overall pressure loss. The result is the evolution of the single and dual curved wall high velocity separator concept. For high temperature particle separation, this concept has been reduced to practice by detailed design, manufacturing and hot testing of the HTPS-1 and HTPS-2. In the following, we will summarize the methodology of design and scaling prior to the presentation of the HTPS and AAM work completed. The latter includes performance data and the conceptual design suitable for integration of the investigated elements into a commercial scale prototype separator.

2.0 TECHNICAL DISCUSSION

2.1 General

The separation of particulates of micron sizes in the range of 1-10 micron diameter is governed by the dimensionless parameters, Λ , which is identified by dimensionless analysis of the fundamental equation of motion of particles in a given flow field. Λ is given by the following equation:

$$\Lambda = \frac{|\vec{v}_p - \vec{v}|}{|\vec{v}|} \left(\frac{L}{\lambda} \right) \quad (1)$$

where

L - characteristic length of separator

λ - momentum range

$$\lambda = \frac{8}{3} \cdot \frac{\rho_s}{\rho} \cdot \frac{\sigma}{C_D}$$

where

ρ_s - density of material contained in particles

ρ - gas density

σ - particle radius

C_D - drag coefficient

$|\vec{v}_p - \vec{v}|$ - scalar slip velocity

$|\vec{v}|$ - scalar gas velocity

$\vec{v}_p$ - actual particle velocity

$\vec{v}$ - actual gas velocity

Equation (1) indicates that λ increases with increasing values of slip velocity and device dimension L . Two methods have been investigated to achieve sufficient slip velocities, which result in reasonable particle trajectories; the latter result in high collection efficiencies. The wedge separator with shock deflection (shown schematically in Figure 1 and the wedge parameters in Figure 2) was studied during Phase I, while the inertial, curved channel configuration is the second separator device. The latter has been selected for detailed experimental investigation during Phase IA and Phase II, since no applications were apparent, which could efficiently utilize the high kinetic energy leaving the wedge separator; i.e., turbine nozzle applications were not pursued in favor

- ① - UPSTREAM CONDITIONS
- ① - NOZZLE THROAT
- ② - UPSTREAM OF OBLIQUE SHOCK
- ③ - DOWNSTREAM OF OBLIQUE SHOCK
- ④ - INLET TO DIFFUSER
- ⑤ - DISCHARGE OF DIFFUSER

HIGH VELOCITY WEDGE SEPARATOR SCHEMATIC

Figure 1

W E D G E P A R A M E T E R S

Figure 2

of stationary devices. For the stationary curved channel configuration, as shown schematically in Figure 3, the Λ relationship is given by the following equation:

$$\Lambda_1 = \alpha_\lambda \sqrt{\frac{R}{\lambda}} \theta \quad (2)$$

where R - mean radius of curvature

θ - turning angle (radian)

λ - momentum range

α_λ - influence coefficient

Equation (2) has been derived for the ideal case of constant tangential gas velocity and assuming the curvature of the gas path is closely related to the curvature of the particle trajectories ($\alpha_\lambda = 1$). While the detailed values, α_λ , can be determined by refined trajectory analysis and experiment, equation (2) is of interest in so far as geometric parameters are predominant. Λ_1 increases directly with the amount of turning and with a square root function of the ratio of radius of curvature to particle momentum range.

Equation (2) can also be rewritten in the following form:

$$\Lambda_1 = \alpha_\lambda \frac{\Delta \times o}{\lambda} \quad (3)$$

where $\Delta \times o$ denotes the total distance traveled by the particle (for which the curved channel unit is designed) from the suction surface to the capture slot being positioned flush with the concave or pressure surface.

Equation (3) indicates that in case trajectory analysis, based on the appropriate geometry chosen, indicates large values of $(\Delta \times o / \lambda)$, the Λ_1 number will be increased. Recalling the dimensionless trajectories of Reference(1), conducted for the wedge separator, we find the following Λ equation:

- 0 - UPSTREAM CONDITIONS
- 1 - NOZZLE INLET
- 2 - CAPTURE SLOT DISCHARGE
- 3 - MAIN STREAM, DIFFUSOR EXIT

HIGH VELOCITY SEPARATOR SCHEMATIC (HTPS)

Figure 3

$$\Lambda_2 = F(M_1, \alpha) \left(\frac{\Delta y / \lambda}{1 + (\Delta x / \lambda)} \right) \quad (4)$$

where $F(M_1, \alpha)$ denotes the ratio of the gas velocity upstream of the oblique shock to the gas velocity downstream of the shock. $F(M_1, \alpha)$ increases rapidly with increasing Mach numbers. For the wedge separator studied by Reference (1), $\Lambda_2 = 54$. $\Delta y / \lambda$ is the dimensionless length along the wedge, while $\Delta x / \lambda$ denotes the dimensionless distance of the particle moving normal toward the wedge. Figure 4 is included for reference of the dimensionless trajectory relationships established for the wedge separator.

The importance of the Λ parameter on collection efficiency can easily be seen from the definition given by equation (1), which for Stokes flow coincides with the Stokes number, Reference (2).

$$St = \left(\frac{\rho_p \cdot u (2\sigma)^2}{18 \mu L} \right) \quad (5)$$

Reference (2) has established by analysis and experiment, that the the collision of particles on a given cascade increases with increasing values of the Stokes number; for our case, this indicates that the collection efficiency increases with increasing values of Λ . It has been found that the overall collection efficiency can be represented by an exponential equation of the following form.

$$\eta_c = e^{\ln a + b \ln \Lambda} \quad (6)$$

where a and b are device constants. Equation (6) can also be expanded to provide the trend of the particle collection efficiency $\eta_i = f(\sigma_i)$. The following equation results:

$$\eta_i = C_1 \cdot e^{(\ln \sigma_i - \ln \sigma_o) / C_2} \quad (7)$$

DIMENSIONLESS TRAJECTORIES $\alpha = 10^\circ$

Figure 4

where σ_0 is the design particle radius and C_1 and C_2 are device constants. For the HTPS-1 (single curved wall high temperature particle separator), the following values of the constants are representative: $C_1 = 0.76$; $C_2 = 6.17$. Figure 5 presents the results of $\eta_i = f(\sigma_i)$, which is based on hot test data. Comparing the above device constants with the data published by Reference (3), we find that the HTPS-1 is performing better than present high efficiency multicyclones, as a matter of fact, the performance is approaching high efficiency electrostatic precipitators. The latter however, cannot be utilized at the 1800°F gasifier conditions.

One of the general and very important questions is: Can the HTPS (high temperature) and AAM results be correlated? Also, what are the scaling relationships? In addition, can the AAM results be applied to future HTPS requirements other than those specified by the present contract.

The result of the Phase I investigation and understanding of the lambda number, Λ , have established the following fundamental criteria, whereby the primed values refer to AAM conditions:

- $M' = M$ same Mach number
- $\Lambda' = \Lambda$
- $K = \frac{n \cdot m_p}{\rho} \ll 1$
- $Re' = Re$

In Reference (1), the solution has been presented for identical particle Reynolds number, where the particle Reynolds number is defined by the equation:

$$Re_p = \frac{2\sigma |\vec{v}_p - \vec{v}|}{\nu} \quad (8)$$

Figure 6 presents the resulting scaling requirements. For example, for $\rho_s'/\rho_s = 1$ (same density of material constituting particle mass) and $p = p_{ambient}$, we find a scale of $L'/L = 25$ is required together with a particle ratio of $\sigma'/\sigma = 4.80$ in order to scale AAM results to HTPS conditions. However, consideration of the basic dimensionless particle vector equation,

L&A HTPS-1 COLLECTION PERFORMANCE
COMPARED WITH CYCLONE PERFORMANCE

Figure 5

SCALING PARAMETERS FOR AMBIENT AIR TESTING

Figure 6

$$\frac{D \vec{v}_p}{D \hat{t}} = \Lambda (\vec{v}_p - \vec{v}) \quad (9)$$

where $\hat{v}$ - denotes velocity dimensionless with a characteristic gas velocity

$\hat{t}$ - dimensionless time

indicates that trajectories will be scaled if $\Lambda' = \Lambda$ regardless whether the particle Reynolds numbers are identical or not. This observation was also verified by calculating hot and cold trajectories utilizing our refined analysis program. For the case, $Re_p' \neq Re_p$ but $\Lambda' = \Lambda$, we find the following scaling relationship:

$$\sigma'/\sigma = \{(L'/L (\rho_s/\rho_s'))\}^{\frac{1}{1+\alpha}} \cdot (\rho'/\rho)^{\frac{1-\alpha}{1+\alpha}} \quad (10)$$

whereby α is the empirical drag coefficient parameter according to the relationship:

$$C_D'/C_D = \frac{Re_p^\alpha}{Re_p'}$$

The α value varies as following for the region of interest.

$Re_p < 1$	$\alpha = 1$
$1 < Re_p < 20$	$\alpha = 0.80$
$20 < Re_p < 800$	$\alpha = 0.59$

Evaluation of equation (10) has indicated that the scale of $L'/L = 1.714$ for the HTPS-1 is a very close approximation with $\sigma'/\sigma = 0.80$ in the range of interest $1 \leq Re_p \leq 20$. In case of the HTPS-2 (dual) with $L'/L = 1$ we have direct match of the particle size.

2.2 HTPS Development

2.2.1 Definition of Test Conditions

Table I summarizes coal gasification processes of interest. Pressures and temperatures are indicated. The Foster-Wheeler process has been selected as representative reference conditions. The Foster-Wheeler process is a two-stage entrained flow slagging gasifier process. The operating temperature in the upper stage is 1800°F and the pressure is 350 psia. The gas produced has a higher heating value of 177 BTU per SCF and the average molecular weight is about 25. The gas composition of the Foster-Wheeler process is as follows:

(Mole Percent)	CO	29.3
	CO ₂	3.3
	H ₂	14.5
	CH ₄	3.5
	H ₂ S + COS	0.7
	N ₂	48.7

The test environment has to simulate the Foster-Wheeler gas composition at 1800°F and 350 psia pressure. For this purpose an appropriate solid propellant grain, APEX 81, has been selected, which is seeded with gasifier effluent particulates as to provide a reasonable simulation of actual gasifier conditions. Figure 7 indicates the general test set up, which has been basically utilized for all HTPS testing. Some variations of the test set up, when testing different configurations, are discussed in more detail in the HTPS-1 and HTPS-2 sections of this report.

2.2.2 Final Design and Fabrication

Figure 8 outlines the design methodology developed for the HTPS design. For given gas conditions (T , p , M , γ) and particle characterization including specification of the density of the material making up each particle of radius, σ_i , and mass, m_{pi} , the design procedure starts with the selection of a desired collection ($\bar{\eta}_C$) and aerodynamic performance ($\Delta p/p$, $\Delta \dot{w}/\dot{w}$). The aerodynamic performance considers total pressure drop as a percentage of the total inlet pressure and the purge flow rate as a percentage of the total flow rate. While the final com-

TABLE I

SUMMARY OF COAL GASIFICATION PROCESS PARAMETERS

(Reference-ERDA-76-304, Quarterly Report, 12/75)

Gasifier	T	P
CO ₂ Acceptor	1500° F	145 psia
Bi Gas	1700° F	1450 psia
Hy Gas	1200° F	1000 psia
Steam-Iron	-	-
Synthane	1400° F	1000 psia
Agglomerating Burner Gas	1800° F	100 psia
Molten Salt	1800° F	145 psia
Westinghouse	1600° F	176 psia
Combustion Engineering	1600° F	15 psia
Foster-Wheeler	1800° F	350 psia *

*Originally 500 psia

HOT GAS SYSTEM TEST SCHEMATIC

Figure 7

METHODOLOGY OF HTPS PARTICLE SEPARATOR DESIGN

mercial design is concerned with the detailed layout of an array of elements, the present design effort was mainly directed toward the element design. With typical performance values:

$$\bar{n}_c \approx 0.90$$

$$2\% \leq \frac{\Delta p}{p_0} \leq 10\%$$

$$10\% \leq \frac{\Delta w}{w_0} \leq 30\%$$

for the particle range $2 \leq 2\sigma \leq 10$ micrometers, the basic design parameter, Λ , device Mach number M , and capture slot area to main channel area are selected. With selection of these three design parameters, the basic geometry of a curved wall HTPS is determined ($R, \theta, \Delta x$). Similarly, the wedge dimensions ($\Delta x, \Delta y, \alpha$) would be established. For the given main dimensions, an appropriate design is drawn and then subjected to a rigorous trajectory analysis, which has been computerized in general form. The trajectory analysis provides the details as far as nozzle inlet contouring is concerned, and where the capture slot should be placed for optimum collection. The trajectory analysis is very sensitive to particle size and particle density. While insufficient experimental evidence is available to make an absolute judgement, whether particles will be sticky at 1800°F or have a tendency to bounce off the hot walls at actual operating conditions, the trajectory analysis program has been written in such general form that the effects can be studied and the design developed with proper judgement of the anticipated conditions. The outcome of the trajectory analysis is the finalization of the main geometric parameters ($R, \theta, \Delta x$) as well as the detailed information of the complete separator geometry and the allowable variation in manufacturing tolerances. Based upon these data, the final element design is accomplished as indicated in Figure 9 for the purpose of providing an operating commercial unit, additional steps are required in the design which leads to a reliable array of elements of the proper long duration erosion resistant material; the array then needs to be integrated with the process of interest. The HTPS-1 and HTPS-2 design is based upon the methodology discussed and presented for clarity in Figure 8.

NOTES: UNLESS OTHERWISE SPECIFIED

1. INTERPRET DRAWING PER ANSI Y14.5.
 2. REMOVE ALL BURRS AND SHARP EDGES EQUIV TO .010 R MAX.
 3. SURFACE ROUGHNESS R_a PER ANSI B46.1
 4. THREADS PER ANSI B1.1 FOR UNIFIED INCH SCREW THREADS.
- △ LUBRICATE O-RING WITH VACUUM GREASE.

ITEM 1, 2, 3 PARTICLE SEPARATOR TEST ASSY

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The detailed design of the final, practical test article evolved in a logical, step by step development process. One of the main objectives was to achieve a design that increases the size of the gas flow channel which the particle must cross in order to arrive at the wall containing the capture slot.

In general, small particles move across the flow stream with great fluid restraint while larger particles, such as 10 micron particles, move across a flow stream to the collection wall with relative ease. In general, the larger particles cross the flow stream and may impact the wall in such a way that they bounce several times and may "skipover" collection slots. In case of 1800°F gasifier conditions, we do not know whether particles will be sticky, plastic or both; thus one can only speculate what the potential degree of possible bouncing of larger particles could be. However, in the AAM environment, this effect can be observed and needs to be taken into account. Smaller particles cross the flow stream and do not rebound significantly from the wall. As a result, a gas purge flow stream can remove small particles entrained with the stream adjacent to a curved wall. Larger purge or bleed flows remove more particles or enhance collection efficiency.

For purposes of discussion, the high velocity particle separator can be considered as consisting of an inlet nozzle, a curved channel and collection slots for removal of purge or bleed flow with entrained particles. A diffuser downstream of the curved channel is used to reduce gas velocity and recover dynamic pressure.

The nozzle may be designed to separate the larger particles, i.e., cause the larger particles to move across the flow stream and impinge on the outer curved wall at the start of the curved channel. With attention to design detail, the shape of the nozzle can be such that a significant concentration of the larger particles can be collected in an appropriately placed primary collection slot located on the outer wall at the beginning of the curved flow channel. It is particularly desirable to collect the larger particles on their first encounter with the outer wall to avoid potential bouncing of the particles.

The inlet nozzle does not significantly centrifuge the smaller particles and additional turning of the flow is required to cause migration of the smaller particles to the outer wall and into the collection slot(s). In the curved channel portion, secondary flows are undesirable because particles trapped in the boundary layer on the outer concave curved surface tend to move inward along the side walls thus moving away from the collection slots. Secondary flows are minimized by having nearly two dimensional curved channels for minimum side wall effect and smooth surfaces to minimize boundary layer thickness. The channel has to be designed for a reasonable range of channel Reynolds number in order to avoid undue flow distortions and separation.

Collection slots or ports are cut into the outer concave wall with a tangential intersection or flush to the curved channel. The collection slot area compared with the channel flow area is generally in the range 10-30 percent. This slot area fraction is greater than the bleed or purge flow fraction thus some external diffusion or eddying may be present at the slot inlet. Collection efficiency tends to increase with the size of the collection slot.

The shape of the curved flow channel may be based upon a constant radius of curvature or on a variable radius of curvature. The variable radius configuration may reduce the tendency of the larger particle to bounce due to the lower angle of incidence at the inlet of the curved channel. Erosion rate of the channel walls is known to be strongly affected by the angle of impact of small particles. Smaller impact angles give lower erosion rates.

The angle subtended by the curved channel is an important design parameter because the larger the turning angle, the larger the transverse motion of particles relative to the gas stream. In one design of separator, the HTPS-2, the turning angle was 90° in one direction, and then 90° in the reverse direction for a total of 180° with the gas flow leaving in the same direction as it entered. The basic configuration is very desirable for an array of elements. In the following the details of the HTPS-1 and HTPS-2 are presented.

2.2.2.1 HTPS-1

Figure 9 presents the final design layout of the single curved channel HTPS-1 design. The mean radius of curvature is $R = 2.00$ inches, the total turning angle, $\theta = 90^\circ$, and the characteristic channel width $\Delta x = 0.14$ inches. The inlet nozzle is shaped as to enhance collection efficiency of the particles in the smaller size range. For the short duration rocket propellant testing, 303 stainless steel was found to be a reasonable material. The HTPS-1 is precision machined from a block of 303 SS. Figure 10 presents a photograph of the finished product. Figure 11 shows the HTPS installed in the hot gas test facility.

2.2.2.2 HTPS-2

Figure 12 presents the final layout drawing of the dual curved channel HTPS-2 design. Recognizing the potential of increased collection efficiency with increased amount of turning, θ , the HTPS-2 was designed for $\theta = 180^\circ$. The mean radius of curvature is $R = 1.00$ inch and the characteristic channel width is $\Delta x_0 = 0.140$. Several collection slots are incorporated. Clean and non-clean (or dirty) channels are identified and arranged for ease of filtration of the discharged and collected material. Figure 13 presents a photograph of the final product, machined from a block of 303 stainless steel. Figure 14 illustrates the installation of the HTPS-2 for hot gas performance evaluation.

2.2.3 Laboratory Evaluation & Support (AAM-Phase IA)

The ambient analog model (AAM) allows evaluation of separator performance at ambient conditions. This includes accurate measurement of total pressure drop as function of the device Mach number; evaluation of the effect of purge port areas as a percentage of the total channel width; the effect of purge velocity to main channel velocity ratio, and more importantly, the investigation of capture slot location and detailed design.

While the initial AAM, as shown in Figure 15, has been directed toward performance evaluation of the wedge separator, the main AAM effort has been concentrated on a low pressure drop curved channel configuration of

TEST ARTICLE ASSEMBLY

COMPLETE TEST SETUP
HTPS-1 & HTPS-2

Figure 13

TEST SET UP, HTPS-1 AND HTPS-2
TEST ARTICLES

Figure 14

AAM With Wedge Separator Working Section

Figure 15

single and dual design. The wedge separator might have been the ideal separator configuration provided the process of interest includes an expansion turbine which could efficiently transform the kinetic energy being discharged from the wedge separator to useful work. Feasibility of the wedge separator has been established during the early AAM investigations. Further investigations will be of interest when a real requirement will materialize for an expander or turbine gasifier process. In the following, the various AAM curved wall configurations are described and the test results and theory is also included for completeness.

2.2.3.1 AAM-1

Figure 16 presents the general AAM schematic. Table II is a summary of the various configurations. A fluidized bed is employed to assure proper particle size distribution at the inlet of the various test sections. The AAM effort is conducted under ambient conditions. The pressure loss caused by the test set up is made up by the variable speed, electric motor driven exhaust blower. The mass collection efficiency is established by the filtration method. The particle distribution is subsequently determined by classification.

Figure 17 presents the layout drawing of the AAM-1 configuration. The AAM-1 accelerated the flow abruptly in the short nozzle and turns the flow in the curved channel separator, whereby the centrifugal force acting on the particles provides the necessary slip velocity for particle separation. Downstream of the separator section, the flow is decelerated in the diffuser section. Figure 18 presents the aerodynamic performance of the AAM-1 as function of Mach number. Good agreement of test and theory has been observed. 3% total pressure losses as a percentage of the separator total upstream pressure is a realistic aerodynamic performance for throat Mach number of about $M = 0.35$. Figure 18 also presents the collection performance as function of the Mach number. Figure 19 shows collection performance as a function of particle size in the range 0.1 micron - 10 micron. Table III summarizes all the AAM tests. Collection efficiencies above 90% are demonstrated with reasonable aerodynamic performance.

Figure 16

T A B L E I I
AAM CONFIGURATION SUMMARY

CONFIGURATION	DRAWING NO.	THROAT DIMENSIONS	DESCRIPTION
AAM-1	L&A 10014	.177 x 1.00 inches	Supersonic - Area Ratio = 1.4; Radius Of Curvature = 2.0 in.; Capture Slot 70° from Throat; Slot Area = 28% of Channel.
AAM-2	L&A 10014	.240 x 1.00 inches	Subsonic - Diffusion Ratio = 1.12; Radius of Curvature = 2.0 in Capture Slot 70° from Throat; Slot Area = 28% of Channel.
AAM-2A	L&A 10014	.240 x 1.00 inches	Modified AAM-2 to Provide Variable Capture Slot Area. Slot Area Varied from 15% to 48%.
AAM-2B	L&A 10015	.249 x 1.00 inches	Modification Added a Primary Capture Slot at Throat. Additional Slot 30° from Throat Was Not Introduced (See Drawing). Modified Inlet.
AAM-3	L&A 10015	.225 x 1.00 inches	Variable Curvature Channel. Two Stages of Separation. First Stage Collection Slot is Located 70° from Throat and Area is 28% of Channel Area. Diffusion Ratio = 1.19.
AAM-3A	L&A 10016	.225 x 1.00 inches	Modifed to Provide Second Stage of Clean Gas Extraction.
AAM-4	L&A 10010	.140 x .50 inches (Dual Channel)	Same Channel Configuration as HTPS-2. Two Stage-Dual Channel

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REVISIONS		DATE	APPROVED
ZONE	LYR		
DESCRIPTION			

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1.00
STK

Figure 17
p. 31

-1		1.00 THK PLEXIGLASS	
QTY REQD	BY	CODE IDENT	PART OR IDENTIFYING NO.
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON DECIMALS		NOMENCLATURE OR DESCRIPTION	
.125 .156 .188 .250 .312 .375 .500 .625 .750 .875 1.000 1.250 1.500 1.750 2.000 2.500 3.000 3.500 4.000 4.500 5.000 5.500 6.000 6.500 7.000 7.500 8.000 8.500 9.000 9.500 10.000		MATERIAL AND/OR SPECIFICATION	
DO NOT SCALE DRAWING		LIST OF MATERIAL	
CONTRACT NO.		LINHARDT AND ASSOCIATES INC.	
DRAWN BY		ENGINEER	
CHECKED BY		DESIGNER	
APPROVED BY		TITLE	
DATE		CENTER PLATE - PARTICLE SEPARATOR	
SCALE		CODE IDENT NO.	
REL DATE		10007	

HTPS-1 AERODYNAMIC AND COLLECTION PERFORMANCE

LEGEND:

- Δ Experimental Data
Collection Efficiency
HTPS-1/AAM
- $\circ$ Experimental Data
Total Pressure Ratio

Figure 18

AAM-1 Configuration

COLLECTION PERFORMANCE

Figure 19

-a-

TABLE III

SUMMARY OF AAM RESULTS

TEST NO.	CONFIGURATION MODEL	PURGE AREA %	PARTICLE TEST SAMPLE	MACH NO.	VELOCITY RATIO PURGE/MAIN	PURGE FLOW %	COLLECTION EFFICIENCY %	COMMENTS
1	AAM-1	27.4	Trona Fly Ash	1.0	.145	4	8	
2	AAM-1	27.4	Trona Fly Ash	1.0	.29	8	51	
3	AAM-1	27.4	Trona Fly Ash	1.0	.29	8	65	Screened Fly Ash 44 micron
5	AAM-1	27.4	Talc*	1.0	.40	11	70	*Merck Talc
6	AAM-1	27.4	NEOSIL A	1.0	.40	11	2.5	Extreme Agglomeration
7	AAM-1	27.4	Glass Beads MS-XLS	1.0	.40	11	26.0	Large Glass Beads
8	AAM-1	27.4	Glass Beads	1.0	.40	11	22	
17	AAM-1	27.4	Trona	1.6	.42	11.6	59.6	
18	AAM-1	27.4	Trona	1.6	.46	11.2	61.1	Screened Fly Ash 44 micron
19	AAM-1	27.4	Talc (Merck)	1.6	.42	11.4	92	
20	AAM-1	27.4	Talc	1.6	.42	11.4	82.1	
21	AAM-1	27.4	Talc	1.25	.46	12.5	84.5	
22	AAM-1	27.4	Talc*	1.25	.46	12.5	89.1	*Mallinckrodt Talc
23	AAM-1	27.4	Talc	1.6	.41	11.3	68.8	

TABLE III

SUMMARY OF AAM RESULTS

-b-

TEST NO.	CONFIGURATION MODEL	PURGE AREA %	PARTICLE TEST SAMPLE	MACH NO.	VELOCITY RATIO PURGE/MAIN	PURGE FLOW %	COLLECTION EFFICIENCY %	COMMENTS
24	AAM-1	27.4	Talc	1.6	.40	11.3	68.8	Electrical Problem Revised Configuration. Conducted Pressure Surveys-Runs 30 through 58
25	AAM-1	27.4	Talc	1.33	.42	11.5	71.4	
26	AAM-1	27.4	Talc	1.5	.41	11.3	66.3	
27	AAM-1	27.4	Talc	1.4	.41	11.2	58.0	
28	AAM-1	27.4	Talc	1.33	.41	11.2	51.6	
29	AAM-1	27.4	Talc	1.6	.42	11.5		
59-2	AAM-2	30.4	Talc	.9	.8	24.0	93.0	
59-3	AAM-2	30.4	Talc	.91	1.0	30.5	95.5	
60	AAM-2	30.4	Talc	.90	1.2	36.0	96.5	
61	AAM-2	30.4	Talc	.70	.8	24.3	95.5	
62	AAM-2	30.4	Talc	.5	.8	24.3	92.7	
63	AAM-2	30.4	Talc	.32	.8	24.3	90.3	
64	AAM-2	30.4	Talc	.3	.8	24.3	84.4	
65	AAM-2	30.4	Talc	.9	.29	8.8	43.4	
67	AAM-2	30.4	Talc	.3	.26	8.0	24.3	

TABLE III

SUMMARY OF AAM RESULTS

-C-

TEST NO.	CONFIGURATION MODEL	PURGE AREA %	PARTICLE TEST SAMPLE	MACH NO.	VELOCITY RATIO PURGE/MAIN	PURGE FLOW %	COLLECTION EFFICIENCY %	COMMENTS
68	AAM-2	30.4	Talc	.7	.375	11.4	54.3	
69	AAM-2	30.4	Talc	.7	.25	7.6	36.0	
70	AAM-2	30.4	Talc	.7	.12	3.6	17.7	
71	AAM-2	30.4	Talc	.3	.53	16.0	70.0	
72	AAM-2	30.4	Talc	.125	1.16	35.3	86.9	
73	AAM-2	30.4	Talc	.125	.72	21.9	80.6	
74	AAM-2	30.4	Talc	.125	.43	13.1	54.1	
75	AAM-2	30.4	Trona (Bulk)	.3	.72	21.9	49.7	
76	AAM-2A	15.2	Talc	.3	1.58	24.0	68.1	
77	AAM-2A	15.2	Talc	.3	.20	3.04	10.8	
78	AAM-2A	15.2	Talc	.86	.53	8.0	86.5	
79	AAM-2A	15.2	Talc	.86	.39	6.0	85.6	
80	AAM-2A	46.1	Talc	.125	.76	35.0	73.8	
81	AAM-2A	46.1	Talc	.125	.85	39.0	91.7	
82	AAM-2A	46.1	Talc	.3	.48	22.0	73.8	
85	AAM-2A	46.1	Talc	.7	1.28	59.0	92.9	
86	AAM-2A	46.1	Glass Beads	.125	1.04	48.0	61.1	5-40 micron beads
87	AAM-2A	46.1	NEOSIL A	.125	1.04	48.0	18.5	

TABLE III

SUMMARY OF AAM RESULTS

-d-

TEST NO.	CONFIGURATION MODEL	PURGE AREA %	PARTICLE TEST SAMPLE	MACH NO.	VELOCITY RATIO PURGE/MAIN	PURGE FLOW %	COLLECTION EFFICIENCY %	COMMENTS
AAM-88	AAM-3		Mallinckrodt	.43				
	1st Purge	20			.69	13.8	17.0	
	2nd Purge	30			1.00	30.0	56.4	
	Overall	50			1.04	52.1	96.2	
AAM-89	AAM-3		Mallinckrodt	.42				
	1st Purge	20			.39	7.8	15.3	
	2nd Purge	30			.95	28.6	60.9	
	Overall	50			.71	35.3	94.1	
AAM-90	AAM-3		Mallinckrodt	.41				
	1st Purge	20			0	0.0	7.6	
	2nd Purge	30			1.03	31.1	59.3	
	Overall	50			.86	43.1	85.2	
AAM-91	AAM-3		Mallinckrodt	.41				
	1st Purge	20			1.12	22.5	74.6	
	2nd Purge	30			1.34	40.1	73.8	
	Overall	50			1.52	76.2	99.4	
AAM-92	AAM-3		Mallinckrodt	.38				
	1st Purge	20			.65	13.0	65.4	
	2nd Purge	30			1.34	40.2	77.1	
	Overall	50			1.13	56.5	98.0	
AAM-93	AAM-3		Trona Fly Ash	.37				
	1st Purge	20			.63	12.6	37.2	
	2nd Purge	30			1.36	40.9	46.5	
	Overall	50			1.12	56.0	89.5	
AAM-94	AAM-3		Trona Fly Ash	.41				
	1st Purge	20			1.12	22.4	48.8	
	2nd Purge	30			1.35	40.4	48.8	
	Overall	50			1.24	62.0	90.0	

TABLE III

SUMMARY OF AAM RESULTS

-e-

TEST NO.	CONFIGURATION MODEL	PURGE AREA %	PARTICLE TEST SAMPLE	MACH NO.	VELOCITY RATIO PURGE/MAIN	PURGE FLOW %	COLLECTION EFFICIENCY %	COMMENTS
AAM-95	AAM-2 *		Mallinckrodt	.21				* Inverted
	Primary	28			.14	3.5	30.1	
	Secondary	21			2.00	41.8	61.5	
	Overall	30			1.46	43.8	74.1	
AAM-96	AAM-2		Mallinckrodt	.19				
	Primary	28			.13	3.7	41.4	
	Secondary	21			1.10	23.1	61.8	
	Overall	30			.86	25.9	77.6	
AAM-97	AAM-2		Mallinckrodt	.19				
	Primary	28			0.0	0.0	11.4	
	Secondary	21			1.06	22.2	64.9	
	Overall	30			.74	22.2	68.9	
AAM-98	AAM-2		Mallinckrodt	.18				
	Primary	28			.27	7.75	56.9	
	Secondary	21			1.18	24.8	71.1	
	Overall	30			1.02	30.6	87.7	
AAM-99	AAM-2		Mallinckrodt*	.18				* Processed Once
	Primary	28			.27	7.6	67.2	
	Secondary	21			1.17	24.6	72.3	
	Overall	30			1.01	30.3	90.7	
AAM-100	AAM-2		Mallinckrodt	.19				
	Primary	28			.51	14.4	69.7	
	Secondary	21			1.00	21.0	81.3	
	Overall	30			1.08	32.4	93.7	
AAM-101	AAM-2		Mallinckrodt	.19				
	Primary	28			1.00	28.0	79.1	
	Secondary	21			1.16	24.3	71.1	
	Overall	30			1.52	45.5	94.0	

SUMMARY OF AAM RESULTS

-f-

TABLE III

TEST NO.	CONFIGURATION MODEL	PURGE AREA %	PARTICLE TEST SAMPLE	MACH NO.	VELOCITY RATIO PURGE/MAIN	PURGE FLOW %	COLLECTION EFFICIENCY %	COMMENTS
AAM-102	AAM-2		Mallinckrodt*	.17				
	Primary	28			.60	16.7	75.7	* Processed Once
	Secondary	21			.95	20.0	80.0	
	Overall	30			1.11	33.4	95.0	
AAM-103	AAM-2		Mallinckrodt	.38				
	Primary	28			.51	14.4	73.7	
	Secondary	21			1.00	21.1	70.0	
	Overall	30			1.08	32.5	92.1	
AAM-104	AAM-2		Mallinckrodt	.18				
	Primary	28			.27	7.5	41.2	
	Secondary	21			1.12	23.6	72.9	
	Overall	30			.98	29.3	84.1	
AAM-105	AAM-2		Mallinckrodt*	.18				
	Primary	28			.27	7.6	57.0	* Processed Once
	Secondary	21			1.14	24.0	76.0	
	Overall	30			2.34	70.2	89.7	
AAM-106	AAM-2		Mallinckrodt*	.18				
	Primary	28			.27	7.6	51.0	* Processed Twice
	Secondary	21			1.14	24.0	80.9	
	Overall	30			.99	29.7	90.6	
AAM-107	AAM -2		Trona Fly Ash	.18				
	Primary	28			.27	7.5	40.7	
	Secondary	21			1.22	25.7	41.8	
	Overall	30			.98	29.3	65.5	
AAM-108	AAM-2		Trona Fly Ash	.18				
	Primary	28			.27	7.5	51.1	
	Secondary	21			.79	23.6	29.1	
	Overall	30			.95	29.3	65.3	
AAM-109								Electrical Outage

-g-

SUMMARY OF AAM RESULTS

TABLE III

TEST NO.	CONFIGURATION MODEL	PURGE AREA %	PARTICLE TEST SAMPLE	MACH NO.	VELOCITY RATIO PURGE/MAIN	PURGE FLOW %	COLLECTION EFFICIENCY %	COMMENTS
AAM-110	AAM-4		Mallinckrodt	.29				
	1st Purge	N/A			N/A	9.7	18.2	
	2nd Purge	37			.54	20.0	37.5	
	Overall	60			.94	56.6	45.5	
AAM-111	AAM-4		Mallinckrodt	.51				
	1st Purge	N/A			N/A	10.6	69.9	
	2nd Purge	37			.55	20.4	44.4	
	Overall	60			1.05	62.8	89.7	
AAM-112	AAM-4		Mallinckrodt	.50				
	1st Purge	N/A			N/A	10.9	74.3	
	2nd Purge	37			.56	20.6	44.4	
	Overall	60			1.06	63.6	82.5	
AAM-113	AAM-4		Mallinckrodt	.39				
	1st Purge	N/A			N/A	7.1	64.7	
	2nd Purge	37			.39	14.3	55.0	
	Overall	60			.95	57.1	79.1	
AAM-114	AAM-4		Mallinckrodt	.36				
	1st Purge	N/A			N/A	11.7	73.1	
	2nd Purge	37			.63	23.4	63.0	
	Overall	60			1.02	61.7	83.9	
AAM-115	AAM-4		Mallinckrodt	.56				
	1st Purge	N/A			N/A	11.5	67.1	
	2nd Purge	37			.62	23.1	60.0	
	Overall	60			1.07	64.3	81.6	
AAM-116	AAM-4		Mallinckrodt	.59				
	1st Purge	N/A			N/A	14.3	72.9	
	2nd Purge	37			.77	28.6	44.4	
	Overall	60			1.07	64.3	82.3	

TABLE III

SUMMARY OF AAM RESULTS

-h-

TEST NO.	CONFIGURATION MODEL	PURGE AREA %	PARTICLE TEST SAMPLE	MACH NO.	VELOCITY RATIO PURGE/MAIN	PURGE FLOW %	COLLECTION EFFICIENCY %	COMMENTS
AAM-117	AAM-4		Mallinckrodt	.42				
	1st Purge	N/A			N/A	3.0	53.2	
	2nd Purge	37			.85	31.6	93.3	
	Overall	60			1.01	60.6	66.8	
AAM-118	AAM-4		Mallinckrodt	.40				
	1st Purge	N/A			N/A	0.0	30.0	
	2nd Purge	37			N/A	0.0	30.0	
	Overall	60			.85	31.6	80.0	
					.99	59.4	56.2	
AAM-119	AAM-4		Mallinckrodt	.41				
	1st Purge	N/A			N/A	25.0	81.8	
	2nd Purge	37			1.08	40.0	63.3	
	Overall	60			1.20	71.9	92.7	
AAM-120	AAM-4		Mallinckrodt	.41				
	1st Purge	N/A			N/A	37.5	86.8	
	2nd Purge	37			.50	18.2	57.1	
	Overall	60			1.20	71.9	93.1	
AAM-121	AAM-4		Trona Fly Ash	.41				
	1st Purge	N/A			N/A	37.5	49.7	
	2nd Purge	37			N/A	37.5	49.7	
	Overall	60			.50	18.2	34.0	
					1.20	71.9	78.2	
AAM-122	AAM-4		Trona Fly Ash	.32				
	1st Purge	N/A			N/A	20.0	35.1	
	2nd Purge	37			.50	18.2	34.0	
	Overall	60			1.07	64.0	77.3	
AAM-123	AAM-4		Trona Fly Ash	.42				
	1st Purge	N/A			N/A	3.0	30.8	
	2nd Purge	37			.98	36.1	42.6	
	Overall	60			1.01	60.6	71.9	

-i-

TABLE III

SUMMARY OF AAM RESULTS

TEST NO.	CONFIGURATION MODEL	PURGE AREA %	PARTICLE TEST SAMPLE	MACH NO.	VELOCITY RATIO PURGE/MAIN	PURGE FLOW %	COLLECTION EFFICIENCY %	COMMENTS
AAM-124	AAM-4		Mallinckrodt	.41				
	1st Purge	N/A			N/A	25.0	71.8	
	2nd Purge	37			1.08	40.0	71.6	
	Overall	60			1.20	71.9	90.5	
AAM-125	AAM-4		Mallinckrodt*	.41				
	1st Purge	N/A			N/A	25.0	74.3	* Processed Once
	2nd Purge	37			1.08	40.0	90.6	
	Overall	60			1.20	71.9	95.4	
AAM-126	AAM-3		Mallinckrodt	.25				Closed
	1st Purge	20			2.5	50.0	87.5	
	2nd Purge	30			0.0	0.0	0.0	
	Overall	50			1.0	50.0	87.5	
AAM-127	AAM-3		Mallinckrodt	.28				
	1st Purge	20			2.27	45.4	66.5	
	2nd Purge	30			1.67	50.0	74.1	
	Overall	50			1.09	54.6	91.3	
AAM-128	AAM-3		Mallinckrodt	.32				
	1st Purge	20			1.13	22.6	71.4	
	2nd Purge	30			1.34	40.1	77.0	
	Overall	50			1.25	62.3	99.5	
AAM-129	AAM-3		Mallinckrodt	.32				
	1st Purge	20			1.13	22.6	54.1	
	2nd Purge	30			1.34	40.1	67.5	
	Overall	50			1.25	62.3	99.4	
AAM-130	AAM-3		Mallinckrodt	.26				
	1st Purge	20			.75	15.0	55.4	
	2nd Purge	30			.83	25.0	61.7	
	Overall	50			1.10	55.0	96.5	

TABLE III

SUMMARY OF AAM RESULTS

-j-

TEST NO.	CONFIGURATION MODEL	PURGE AREA %	PARTICLE TEST SAMPLE	MACH NO.	VELOCITY RATIO PURGE/MAIN	PURGE FLOW %	COLLECTION EFFICIENCY %	COMMENTS
AAM-131	AAM-3A		Mallinckrodt	.28				*Clean Gas Extraction
	1st Purge	20			.69	13.8	53.4	
	2nd Purge	30			.33	10.0	26.1	
	CGE*	N/A			N/A	40.0	27.0	
	Overall	50			1.19	59.6	97.6	
AAM-132	AAM-3A		Mallinckrodt	.30				
	1st Purge	20			.69	13.8	53.3	
	2nd Purge	30			.33	10.0	33.9	
	CGE	N/A			N/A	30.0	16.1	
	Overall	50			1.19	59.6	96.4	
AAM-133	AAM-3A		Mallinckrodt	.30				
	1st Purge	20			.69	13.8	54.9	
	2nd Purge	30			.33	10.0	32.3	
	CGE	N/A			N/A	40.0	22.9	
	Overall	50			1.19	59.6	97.3	
AAM-134	AAM-3A		Mallinckrodt	.28				
	1st Purge	20			.74	14.8	56.3	
	2nd Purge	30			.39	11.8	37.1	
	CGE	N/A			N/A	17.6	6.7	
	Overall	50			1.13	56.7	92.7	
AAM-135	AAM-3		Mallinckrodt	.29				
	1st Purge	20			.89	17.9	56.3	
	2nd Purge	30			.70	21.0	56.0	
	CGE	N/A			N/A	21.0	11.0	
	Overall	50			1.21	60.5	95.0	
AAM-136	AAM-3A		Mallinckrodt	.28				
	1st Purge	20			.68	13.6	54.8	
	2nd Purge	30			.83	25.0	57.6	
	CGE	N/A			N/A	12.5	5.0	
	Overall	50			1.00	50.0	92.4	

-k-

SUMMARY OF AAM RESULTS

TABLE III

TEST NO.	CONFIGURATION MODEL	PURGE AREA %	PARTICLE TEST SAMPLE	MACH NO.	VELOCITY RATIO PURGE/MAIN	PURGE FLOW %	COLLECTION EFFICIENCY %	COMMENTS
AAM-137	AAM-3A		Mallinckrodt	.28				Introduced anti-circulation baffle * Clean Gas Extraction
	1st Purge	20			.67	13.6	55.8	
	2nd Purge	30			.83	25.0	54.1	
	CGE*	N/A			N/A	12.5	7.3	
	Overall	50			1.00	50.0	96.6	
AAM-138	AAM-3A		Mallinckrodt	.26				
	1st Purge	20			.55	11.0	50.7	
	2nd Purge	30			.83	25.0	66.1	
	CGE	N/A			N/A	12.5	2.5	
	Overall	50			.81	40.4	93.2	
AAM-139	AAM-3A		Mallinckrodt	.26				
	1st Purge	20			.44	8.8	55.2	
	2nd Purge	30			.68	20.4	59.8	
	CGE	N/A			N/A	55.6	19.6	
	Overall	50			.67	33.6	93.7	
AAM-140	AAM-3A		Mallinckrodt	.27				
	1st Purge	20			.275	5.5	39.1	
	2nd Purge	30			.69	13.7	22.8	
	CGE	N/A			N/A	76.5	34.6	
	Overall	50			.58	28.8	88.4	

2.2.3.2 AAM-2

Figure 20 presents the AAM-2 layout drawing and Table II summarizes the characteristics of this configuration. This design is similar to AAM-1 however, it has been altered in contour shape for near constant subsonic flow velocity in the curved channel. The height of the throat at the minimum flow area section was increased from .177 to .240". Thus the particles must cross a significantly wider channel to reach the concave wall and the bleed slot. The bleed slot is located after 70° of wall curvature measured from the entrance of the separator. An adjustable bleed capture slot width is provided and experiments were conducted over a range of slot/total flow passage area from 15%-50%.

A modification to the AAM-2 was made, AAM-2B, wherein an additional or primary slot was incorporated adjacent to the throat. The details of this slot are shown in Figure 21. (L&A Drawing 10015). It should be noted that only the throat slot was added although the drawing shows two additional slots.

Figure 22 presents the effect of velocity ratio and Mach number on collection efficiency for the AAM-2 configuration with a capture slot width of 30.4 percent. The velocity ratio is defined as ratio of the velocity of the capture slot or purge flow to the velocity of the main flow at the plane of the location of the entrance of the capturing slot. The velocity ratio appears to have a strong influence on collection performance. Velocity ratios of about unity indicate most desirable performance. The width of purge slot was varied to determine the effect of the capture slot percent on the collection efficiency with purge area percentage. The slope flattens as the collection efficiency approaches 100%.

AAM-2B has a primary collection slot adjacent to the nozzle and the secondary slot is the conventional bleed slot. In Figure 24, the collection efficiency is shown as a function of velocity ratio, i.e., the ratio of slot velocity to stream velocity. The curve labeled "secondary" is the local separation efficiency at the secondary slot. The overall collection performance is the sum of the particulates collected by both slots shown at the same velocity ratio as the primary slot. The primary slot tends to capture predominantly larger particles and the secondary slot captures predominantly

EXPERIMENTAL PERFORMANCE RESULTS

AAM-2

Effect of Velocity Ratio and Mach No.
on Collection Efficiency

Figure 22

EXPERIMENTAL PERFORMANCE RESULTS

AAM-2
Effect of Purge Area on
Collection Efficiency

Figure 23

COLLECTION PERFORMANCE

A A M - 2B

Figure 24

smaller particles.

The AAM collection performance was mainly conducted with talc of particle size ranging from 0.20 to 10 micron as defined by the electron scanning microscope. The particle size distribution was controlled by improvements made in the fluidized bed feed system and better control of humidity. Agglomeration of particles in the fluidized bed experienced during the initial work was most likely due to high humidity weather.

Talc has been selected as the reference particulate material due to its good record in previous particle flow work, i.e., the closeness of its density value to coal particles and the ease of handling and being readily available. Table IV lists particles considered for testing. Using talc particles with the AAM, we found excellent collection performance for small particles and sometimes decrease of collection performance for larger particles (about 10 micron). In order to identify this phenomenon, not being observed in the hot HTPS runs, AAM investigations were carried out with different particle materials such as glass beads, Trona Fly Ash, Neosil "A"; the density of all these materials was nearly identical to the talc or coal particles of interest. The variation in particle material and particle configuration demonstrated certain variations in collection efficiency, as seen in Table V. The latter appear to be related to a possible bouncing phenomenon of the larger particles off the plexiglass walls. The glass spheres gave the strongest indication of the probable validity of the bouncing hypothesis. Therefore, an analysis was initiated, which supported the hypothesis for spherical particles and having flow situations without boundary layer damping. While the high temperature environment might present the opposite phenomenon, that means stickiness of particles due to elevated temperature, it has become advisable to investigate and establish bouncing parameters, the latter are basic design criteria for the final conceptual design of the HTPS.

Particle size distribution or characterization has been determined for the various particle samples of interest. This is normally accomplished using a scanning electron microscope with a Vidicon attachment and a Cambridge image analyzer. An example of particle size characterization is presented in Table VI for talcum. The characterization was performed for the particle material for the feed, purge (bleed) collection and mainstream discharge collection. The characterization is

TABLE IV
PARTICLE EVALUATION

PARTICLE DESCRIPTION	γ	SIZE RANGE	MICROSCOPIC APPEARANCE	RESULTS		COMMENTS
				BLEED %	RECOVERY %	
Trona Fly Ash	2.7	2 - 44 μ	Granular/ Spherical	3 runs 4 8 8	@ M=1.0 8 51 65	Particles screened prior to use. Materials agglomerates after screening
Arizona Fine Road Dust	2.65	1 - 3 μ narrow band	Granular Spherical	1 run 8	@ M=1.0 0	Forms solid cake when used in moist air. Cannot use material. No feed achieved.
Talcum Powder "Merck"	2.7	19% < 1.0 μ 58% 1-10 23% > 10 μ	Granular Prismatic	1 run 11	@ M=1.0 70	Successful particle feeding. Do not know whether agglomeration was occurring in the passage.
Neosil "A" (Silica Particles)	2.65	0 - 10 μ (1% above 10 μ , 40% below 2 μ)	Granular	1 run 11	@ M=1.0 2½	Very little separation. Observed agglomeration of material, cannot use.
Glass Beads	2.42	5 - 44 μ	Spherical	1 run 11 1 run 3	@ M=1.0 26 @ M=0.35 22	Useful to eliminate agglomeration and ideal for modeling purposes. Need to minimize or eliminate material above 10 .
Talcum Powder "Mallinckrodt"	2.67	15% < 0.5 μ 15% 0.5-1.0 μ 28% 1.0-3.0 μ 36% 3.0-10 μ 7% > 10 μ	Granular/ Prismatic/ Spherical	Multiple Runs at Various Mach No. Ranging from M = 0.1 to 1.0		Excellent material for cold flow laboratory experiments.

COMPARATIVE PERFORMANCE OF VARIOUS PARTICULATES

TABLE V

CONFIGURATION	PURGE FLOW PERCENT	MACH NO.	PARTICLE SAMPLE	COLLECTION EFFICIENCY PERCENT
AAM-1	12.5	1.25	Talc*	89.1
AAM-1	11	1.00	Talc**	70.0
AAM-1	11	1.00	NEOSIL "A"	2.5
AAM-1	48	.125	NEOSIL "A"	18.5
AAM-1	8	1.00	TronaFlyAsh	51
AAM-1	8	1.00	TronaFlyAsh	65
AAM-1	11	1.00	GlassBeads	22

Variable Curvature Channel				
AAM-3	22.6	.41	Talc*	74.6
AAM-3	22.4	.425	TronaFlyAsh	48.8
AAM-3	62.3	.42	Talc*	99.4
AAM-3	62.0	.425	TronaFlyAsh	90.0
AAM-3	13.0	.38	Talc*	65.4
AAM-3	12.6	.38	TronaFlyAsh	37.2
AAM-3	56.4	.38	Talc*	97.3
AAM-3	56.0	.38	TronaFlyAsh	89.5

* Mallinckrodt Talc

** Merck Talc

TABLE VI

TYPICAL SIZE DISTRIBUTION ANALYSIS

USING A

CAMBRIDGE IMAGE ANALYZER

SAMPLE I (Feed Material Fluidized Bed)-Mallinckrodt (6, 958 particles measured)

Size Range		Preparation A	Preparation B
< 0.1	Micron	7.2 %	7.0 %
0.1-0.5	"	9.0 %	8.4 %
0.5-1.0	"	15.0 %	10.1 %
1.0-3.0	"	28.5 %	27.5 %
3.0-10.0	"	34.2 %	40.0 %
>10.0	"	7.1 %	7.0 %

SAMPLE II (Bleed Flow) AAM-1 (7,570 particles measured)

Size Range		Preparation A	Preparation B
< 0.1	Micron	6.5 %	8.0 %
0.1-0.5	"	12.5 %	9.2 %
0.5-1.0	"	22.0 %	19.1 %
1.0-3.0	"	34.1 %	38.0 %
3.0-10.0	"	19.5 %	18.0 %
> 10.0	"	5.4 %	7.7 %

SAMPLE III (Main Stream Discharge Flow) AAM-1 (5,925 particles measured)

Size Range		Preparation A	Preparation B
< 0.1	Micron	0.5 %	1.0 %
0.1-0.5	"	1.0 %	0.8 %
0.5-1.0	"	15.0 %	15.0 %
1.0-3.0	"	28.0 %	25.9 %
3.0-10.0	"	45.0 %	41.0 %
>10.0	"	13.0 %	10.1 %

utilized to determine the collection efficiency of each specific particle size. Using the data from Table VI, an analysis was performed for measured overall collection efficiency values of close to 99%. The analysis indicates high collection performance for particles below 2 microns in diameter. The performance decrease for larger particles is probably due to the bouncing phenomenon and the fact that the AAM configuration has been designed for high collection efficiencies of the smaller particulates.

Experiments were conducted with AAM-2B to determine the collection efficiency for each collection slot as a function of particle size and also as a function of particle size distribution in the feed stock. The first experiment was performed conventionally (Test 98) while an additional test (Test 99) was performed using feedstock obtained from the primary collection slot of Test 98. Particle size characterization of all of the samples was obtained using an aerodynamic impactor. The characterization results are presented in Table VII. The collection performance is presented graphically in Figures 25 and 26.

2.2.3.3 AAM-3 Variable Curvature

The AAM-3 design objective was to minimize the angle of impact of the larger particles thus reducing the tendency for these particles to bounce and miss the capture slot located at 70° from the nozzle throat. The design is shown in Figure 27 (L&A Dwg 10016). The original version had a variable curvature channel with a purge (bleed) capture slot, a through flow stream (dirty main) and a clean gas extraction stream. The through flow stream (dirty main) flows into a second reversed curved channel with a purge (bleed) flow slot and a main flow collector. A secondary clean gas extractor slot was added as a modification.

Figure 28 shows the collection performance of the AAM-3 as a function of velocity ratio which is defined as the slot velocity divided by the main stream velocity. The primary collection slot curve is based on total flow while the secondary collection slot data is on local conditions of second stage flow. The overall data is based on a summation of the material collected from both stages and the velocity ratio of the primary slot.

It is noteworthy that the AAM-3 demonstrated superior overall collection efficiency when compared to the other AAM configurations.

TABLE VIITYPICAL CHARACTERIZATION OF PARTICLE SIZE
BY AERODYNAMICS USING ANDERSEN IMPACTOR

PERCENT MASS DISTRIBUTION (Test 98)				AAM-2B
PARTICLE DIAMETER -MICRONS	*FEEDSTOCK* MALLINCKRODT TALCUM	PRIMARY COLLECTION	SECONDARY COLLECTION	MAIN STREAM
>11.0	82.89	89.8	76.0	81.06
11.0- 4.7	7.29	3.3	10.1	9.68
4.7- 2.1	8.17	3.3	11.1	8.17
2.1- 1.1	1.45	0.8	1.7	1.01
< 1.1	0.20	2.8	1.1	0.08

PERCENT MASS DISTRIBUTION (Test 99)				AAM-2B
PARTICLE DIAMETER -MICRONS	*FEEDSTOCK* MALLINCKRODT REPROCESSED	PRIMARY COLLECTION	SECONDARY COLLECTION	MAIN STREAM
>11.0	(Talc used	93.5	83.3	87.8
11.0- 4.7	from Primary	4.6	10.3	7.8
4.7- 2.1	Collection	1.7	5.2	3.4
2.1- 1.1	of Test 98)	0.1	0.7	0.6
< 1.1		0.0	0.5	0.4

PERCENT MASS DISTRIBUTION (Test 115)				AAM-4	
PARTICLE DIAMETER IN MICRONS	*FEEDSTOCK* MALLINCKRODT TALCUM	FIRST STAGE COLLECTION	SECOND STAGE COLLECTION	SECOND STAGE MAIN STREAM	FIRST STAGE MAIN STREAM
>11.0		79.8	81.2	83.9	86.3
11.0- 4.7		9.5	8.8	8.1	7.0
4.7- 2.1		9.1	7.4	6.6	5.6
2.1- 1.1		1.3	1.5	1.0	0.7
< 1.1		0.3	1.1	0.4	0.4

Figure 25

AAM-2B CONFIGURATION
COLLECTION PERFORMANCE

Figure 26

Figure 27
p. 59

QTY REQD		SYM	CODE IDENT	PART OR IDENTIFYING NO.	REWORK/REPLACEMENT OR DESCRIPTION	NATIONAL AND/OR SPECIFICATION	ZONE	FROM NO.
LIST OF MATERIAL								
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. FRACTIONS SHALL BE IN 16ths OF AN INCH. DECIMALS SHALL BE IN 10ths OF AN INCH. DO NOT SCALE DRAWING.					CONTRACT NO.			
FACTORY					DRAWN BY SHAFER			
TOLERANCES					CHECKED BY			
FINISHES					REVISION			
MATERIAL					REVISION			
APPROVAL					REVISION			
APPLICATION					REVISION			
ASSEMBLY NO.					REVISION			
SCALE					REVISION			
DATE					REVISION			
SHEET					REVISION			

LINHART AND ASSOCIATES INC. NEWPORT, CALIFORNIA	
TITLE VARIABLE CURVATURE PARTICLE SEPARATOR AAM-3	
QTY REQD E	FROM NO. 10016
SCALE 1"	SHEET 1

AAM-3 CONFIGURATION
COLLECTION PERFORMANCE

Figure 28

2.2.3.4 AAM-4 Configuration

The AAM-4 is identical to the HTPS-2 in contour, however, the channel width is 0.500 inches. The HTPS-2 design is shown in L&A Drawing 10010, Figure 29. As illustrated in Table II, the AAM-4 flow channels are much smaller than the corresponding flow channels in the other AAM configurations. The smaller dimensions were expected to enhance the collection performance of this unit. The collection efficiency as a function of velocity ratio, Figure 30, and as a function of particle size, Figure 31, show that the performance of the primary collection slot is similar to those for the other AAM configurations. The secondary slot collection efficiency is defined as the mass of particulate collected by the slot divided by the total mass of particulate immediately upstream of the slot.

The lesser performance of the secondary capture slot may be due to boundary layer separation in the reversed curvature portion of the device. The through flow stream inlet conditions are strongly affected by the flows bleed off at the primary collection slot and clean stream. Flow separation at the side walls could cause gross turbulent mixing which would result in a significant reduction of secondary slot collection performance.

The experimental performance data for the AAM-4 configuration with several types of particles is presented in Figure 30. The curve labeled 'Secondary Collection Slot' is based on local conditions of secondary flow. The overall mass collection efficiency of the configuration is shown for normal talcum, coal derived Trona fly ash, and processed talcum. The processed talcum used as feedstock for these experiments was collected from the primary collection slot of previous tests of the AAM-4 configuration. Experiments using feedstock of twice processed talcum yielded no further gain in collection efficiency.

A computer analysis showing the effect of hardware scaling for various size particles is given in Figure 32. The AAM-4 has a suction radius of 1.0" and a throat height of 0.140". From this curve it would be expected that approximately 2/3 of the 2 micron diameter particles would be collected by the primary capture slot and the remainder of the 2 micron diameter particles would be collected by the secondary capture slot. Larger particles easily cross the radial dimension of the channel (.140") and should all be captured.

Figure 29
p. 62

AAM-4

COLLECTION PERFORMANCE

Figure 30

AAM-4 CONFIGURATION
COLLECTION PERFORMANCE

Figure 31

SCALING - EFFECT OF SUCTION RADIUS
ON RADIAL DISPLACEMENT OF PARTICLE

Figure 32

2.2.4 HTPS Test and Evaluation

Table VIII presents a summary of all HTPS tests being conducted during the performance of the present contract. All together fourteen (14) hot firings at 1800°F-2100°F and pressures of 800-100 psia have been conducted. The conclusion is that the HTPS designs evaluated performed reliably and separated 2-10 micron particulate with overall efficiency as high as 90%. As the hot gas test program progressed, improved techniques for testing and evaluation were derived. In the following are described the test setup of each device, the test run, and the subsequent evaluation of the HTPS hot collection performance.

2.2.4.1 HTPS-1

According to Table VIII, Test #1 and Test #2 were gas generator checkout tests with seeded grains. The gas generator is being utilized for simulation of the real high temperature and pressure contract reference gasifier environment. The test article, HTPS-1, was first subjected to hot firings during Tests #3 and #4. Plugging of a bleed flow control orifice which was located ahead of the filter occurred. This problem was overcome by moving the orifice downstream of the filter. This resulted in successful Test Runs #5 and #6. The test setup is shown in Figure 33.

The main flow stream incorporated a cooling coil ahead of two parallel large filters. The filter cartridges were intact at the conclusion of the tests and each had collected solid particulate. Figure 34 shows the HTPS-1 post test.

Detailed analysis of the solid particulate collected on all filters has indicated the following:

- The solid grain has 5.79 percent solid carbon in the gas stream according to HOLEX.
- The grain was seeded with 2 percent ash, either Trona Fly Ash or Rapid City Pilot Plant Particulate
- Filter samples of particle separator main and bleed flows showed significant differences in carbon-to-ash particulate ratio by weight.
- The size distribution of ash residue from the main and bleed is not significantly different.

HOT GAS FIRINGS

T A B L E VIII

SUMMARY EVALUATIONS

DATE	TEST NO.	TEST ARTICLE	PRESSURE PSIA	TEMPERATURE °F	PARTICULATE SAMPLE	COMMENTS
1/11/79	1	Gas Generator	400-500	1900	Trona Fly Ash	Checkout Firing of Particle Seeded Grains
"	2	"	" "	"	Rapid City Particulate	" " " "
3/7/79	3	HTPS-1	400-500	1950-2100	Trona	Generally successful. Plugged Flow Control Orifice Upstream of Filter
"	4	"	" "	" "	Rapid City	
5/18/79	5	HTPS-1	600	1750	Trona	Carbon Ratio Analysis for Particle Collection Efficiency Added Filters to Test Setup 3% Bleed Flow
"	6	"	"	"	Rapid City	
7/31/79	7	HTPS-1	500-600	1950	Trona	Collected Particulate in Filters Increased Bleed Flow to 6%
8/1/79	8	"	800	2150	Rapid City	
9/9/79	9	HTPS-1	300	1950	Trona	Grain Burns from One End Only Gas Generator burns at 500 psi
"	10	"	300	1950	Rapid City	
9/26/79	11	HTPS-1 Series	200	No Data*	Trona	Clean Stream-Very Clean, Collection Efficiency on Tests Correlate w/AAM Cold Test Data 76% Collection Efficiency for 2.5% Bleed Flow
		HTPS-2	100			
	12	HTPS-1 Series	200	2000	Rapid City	
		HTPS-2	100			
11/13/79	13	HTPS-2	100-200	2000	Trona	Increased Bleed Flow Fraction
	14	"	90-100	1800		

*Thermocouple failure-no data recorded

HTPS-1 TEST SET-UP, SCHEMATIC

Figure 33

With the reasonable assumption that one specific sample each of the inlet, bleed and discharge is representative for the total particulate at each location, it is possible to evaluate the total collection efficiency for the particle distribution range 0.10 micron - 10 micron. For this purpose, the sample is first weighed consisting of seeded particulate and carbon, and then a second measurement is taken of the sample having the carbon removed by combustion. This measurement provides appropriate ratios of particulate to carbon, $(m_p/m_c)_i$ at each location. The following ratios, $a_i = (m_p/m_c)_i$ have been obtained, where, i , identifies the location:

- 1 - inlet to test section
- 2 - bleed or collection port
- 3 - discharge of main stream

The coefficients, a_i , are as following:

$$a_1 = 0.35$$

$$a_2 = 1$$

$$a_3 = 0.0625$$

The collection efficiency is defined by the relationship

$$\eta = \frac{m_{p2}}{m_{p2} + m_{p3}}$$

which reduces to the following equation using the particle to carbon mass ratios, a_i :

$$\eta = \frac{1}{1 + \left(\frac{a_3}{a_2}\right) \left(\frac{a_2 - a_1}{a_1 - a_3}\right)}$$

The data obtained permit a calculation of collection efficiency of the HTPS-1.

With the measured a_i values, the collection efficiency is $\eta = 0.87$ for $0.2 < 2\sigma < 10$. Measurement of the carbon content at each location determines the ratio of carbon at the discharge and the bleed port. Using the a_i data, the carbon ratio is given by the following equation:

$$\frac{m_{c3}}{m_{c2}} = \frac{a_2 - a_1}{a_1 - a_3}$$

The ratio is $m_{c3}/m_{c2} = 2.24$. The carbon content is distributed in the 0.16-0.20 micron range throughout the propellant effluent at location 1. The collection efficiency of the submicron cloud is found to be $\eta = 0.32$ based upon the above data and the known amount of carbon at the inlet. With the particulates and carbon collection efficiencies measured we can make a comparison of the effectiveness of the HTPS-1 with present state-of-the-art multi-cyclones and high efficiency cyclones. The comparison is presented in Figure 35, where the collection efficiencies, $\eta_i = f(\sigma_i)$ are plotted versus the particle diameter 2σ (μ). Figure 35 indicates that the HTPS-1 performance is superior to all state-of-the-art cyclones. The carbon method has been checked with the filter collection method of Tests #11 and #12, and favorable correlation has been obtained. It is interesting to note that the HTPS-1 is performing efficiently even outside of the contract particle size range below 2 micron diameter. Figure 36 presents aerodynamic performance, derived from the AAM task, and collection performance, determined by HTPS and AAM measurements. The data are shown as a function of the throat Mach-number. The aerodynamic performance is also compared with theory. Again, favorable correlation is obtained. Figure 36 indicates that low pressure drop performance can be obtained with reduced Mach-number, while the collection efficiency does not decrease drastically. For example for a 3% pressure drop we find the collection efficiency will be about 90% instead of 98% for Mach-number close to unity.

2.2.4.2 HTPS-2

According to Table VIII Tests #11 and #12 provided good performance information. Figure 14 presents a photograph of the test setup of the test article. As shown, a series flow test was conducted concurrently with the HTPS-1.

L&A HTPS-1 COLLECTION PERFORMANCE
COMPARED WITH CYCLONE PERFORMANCE

Figure 35

HTPS-1 AERODYNAMIC AND COLLECTION PERFORMANCE

LEGEND:

- Δ Experimental Data
Collection Efficiency
HTPS-1/AAM
- Experimental Data
Total Pressure Ratio

Figure 36

For Test #11 and #12, the modified grain was utilized, which was developed for Test #9 and #10. The grain was modified to eliminate a central hole which had inhibitor and an insulator adjacent to the outlet flow end closure. With these modifications, the grain burns from one end only; thus the period of burn is doubled and the gas flow rate halved. To burn at the same chamber pressure and temperature, the gas generator control orifice area was reduced by a factor of two. The modified grain and gas generator performed satisfactorily and the total solids collected by the filters was within 10 percent of the expected values (1 gram).

The series flow test was conducted with the HTPS-1 operating at approximately 200 psia and the HTPS-2 at 130 psia with a gas temperature of 1900-2000°F. The duration of the Trona Fly Ash seeded grain was 10.6 seconds and the Rapid City Pilot Plant ash, approximately 7 seconds.

Collection efficiency results can be calculated directly from the weight increases in each of the filters during the test corrected by the carbon plus moisture measured in the laboratory sampling analysis. The laboratory sample analysis also provides an appraisal of the size distribution of the particles in each filter.

The results from the HTPS-2 Tests #11 and #12 are most interesting. A photograph, Figure 37, of the HTPS-2 opened up post test clearly shows the flow passages and collection channels. The hot gas flow enters the test article from the left and splits into two passages. The first curved channel or turn of approximately 90° occurs with the flow in 2 channels and the second reversed flow turn of 90° occurs with the flow in 4 channels. The particle bleed slot flows are taken from 2 similar main channels and the other main flow channels do not have bleed slots. The main flow channels without bleed slots are referred to as "clean" flow channels and the other two main channels are referred to as "dirty" flow channels. The first pair of bleed slots are referred to as 1st bleeds and the 2nd pair of bleed slots are the 2nd bleeds. The paired flow streams are externally manifolded together and lead to single filters.

The overall collection efficiency was 76% for a bleed flow ratio of 2.5%. For a bleed flow ratio of 50%, the collection efficiency was determined to be 99%. From cold testing, it is known that the collection efficiency is a function of the bleed flow ratio, i.e., the collection efficiency increases rapidly as the bleed flow ratio becomes greater than zero and changes very slowly at high bleed ratio. The results from this test coincides with the AAM investigation.

HTPS-2 POST TEST
TEST ARTICLE

Figure 37

Tests #13 and #14 were intended to obtain additional data with increased first bleed flow fraction. While the hot testing was successful, the results indicated flow separation. The latter upsets the collection performance. This has been confirmed by detailed AAM investigations (AAM-4).

2.2.4.3 Collection Performance

Figure 38 presents the collection efficiencies obtained with the HTPS-1 and HTPS-2. The collection efficiency increases with increased values of Λ . (For HTPS-1, $\Lambda = 26.5$ and for HTPS-2, $\Lambda = 70$). For the particle size range $2 < 2\sigma < 10(\mu)$ and the turning concept employed the two data points are on the curve represented by the following equation.

$$\eta_c = e^{-0.5288 + 0.12 \ln \Lambda}$$

This equation is only valid for value of $\Lambda \leq 80$. Larger values do not tend to increase the collection efficiency. The HTPS-1 data point has been determined by the carbon ratio method as outlined in Section 2.2.4.1. The HTPS-2 data point is based upon the fact that the clean channel demonstrated nearly 100% efficiency and the dirty channel experienced some flow separation with subsequent degradation of the efficiency. However, based upon the results of the clean channel and the AAM investigations, we can conclude that the realistic HTPS-2 efficiency should be 98% provided the location of the capture slot is re-located in the second turn and flow separations are avoided. This may be accomplished by refined channel geometry, and increase of channel Reynolds number.

Figure 39 presents the comparison of theoretical particle collection efficiencies as function of particle radius over the range $0.5 \leq \sigma \leq 5\mu$. The experimental evidence and AAM data are also shown for comparison.

2.2.5 Detailed Conceptual Design

2.2.5.1 Stationary Applications

For stationary applications, Figure 40 presents the detailed conceptual design of the selected dual HTPS-2 separator. The conceptual design has been prepared for a subscale laboratory application. The unit will clean up 2 lb/sec of gasifier flow according to the contract requirements.

Figure 38

COLLECTION PERFORMANCE AS FUNCTION OF PARTICLE RADIUS

σ_i (microns)

Figure 39

Figure 40
p. 79

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The conceptual design consists of 20 HTPS-2 elements and is ideally suited to be mounted in the piping at the discharge of the subject gasifier. Inlet and discharge are in the same direction, while the particulate collected with purge flow will be discharged perpendicular to the plane shown in Figure 40. The overall dimensions of the unit are 20 inches in height, 2 inches in width and 10 inches in length. The material selected for the elements is 304 S.S. (machined) or INCO 718 (cast). The elements may be machined or precision investment cast. The tolerances required are well within the investment casting method developed for gas turbine stator and rotor blades by the gas turbine/aerospace industry. Ceramic materials such as silicon carbide are superior to the above materials from a corrosion and erosion standpoint, however, a development program would be required to demonstrate techniques for using this method.

2.2.5.2 Rotating Application

For turbine applications, it is feasible to design the stator as a high velocity separator. The purpose of the stator is to accelerate the flow for power extraction in the rotor. Therefore, the diffuser loss, encountered in the stationary design, is absent and both methods, turning and wedge separation, or the combination of both, can successfully be applied. Figure 41 presents the conceptual design of the HTPS-3 array. The array consists of a cascade of stator blades being equipped with a primary collection slot, intended for large particles; a secondary capture slot downstream of the 120° turning section designed for the smaller particles. In addition, the secondary capture slot is designed as a wedge, which makes additional wedge separation feasible prior to entering the rotor cascade. The wedge collection slot is placed near the trailing edge section of the stator air foil. The rotating application needs to be evaluated in a separate development program related to a gasifier process, which utilizes a gas turbine and/or expansion turbine.

3.0 SUMMARY AND RECOMMENDATIONS

The design, manufacturing, ambient and hot testing of the subject high velocity particulate separator element has been completed successfully. Two concepts have been developed; one, the wedge separator and the other, the curved wall separator. While the supersonic wedge separator needs to be incorporated with the nozzles of an expansion or gas turbine for optimum performance, the curved wall separator is designed for stationary installations.

FIG. 38 CONCEPTUAL DESIGN OF STATOR SEPARATOR FOR TURBINE APPLICATION

Figure 41
p. 81

QTY	REQD	BY	CODE	RELT	PART OR IDENTIFYING NO.	RECOMMENDATION OR DESCRIPTION	MATERIAL AND/OR SPECIFICATION	DATE	REV
LIST OF MATERIAL									
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON DECIMALS						CONTRACT NO.	LINDBART AND ASSOCIATES INC. REVEL, ILLINOIS		
FRACTIONAL						DESIGNER	TITLE		
DECIMALS						CHECKED	CONCEPTUAL DESIGN OF STATOR SEPARATOR FOR TURBINE APPLICATION		
DO NOT SCALE DRAWING						ENGINEER	CODE		
TREATMENT						PROJECT	DATE		
PROJECT						DATE	10017		
DRAWING NO.						SCALE	REV		
APPLICATION						DATE	E		

Since the Foster Wheeler process, selected as reference process for our investigations, does not utilize expansion turbines, the Phase II and Phase IA effort was directed toward development and demonstration of suitable curved channel high temperature particle separators (HTPS). The result has been encouraging: collection efficiencies have been achieved which exceed present multicyclone efficiencies and nearly approach electrostatic precipitator performance. However, the electrostatic precipitators are not suitable for 1800°F and 350 psia pressure operation; and hence the L&A HTPS is the logical separator candidate to be installed in the future in an appropriate pilot plant. For this purpose the design methodology is applicable to design the required element, which needs to be combined into an array of elements as to meet the plant flow rate requirements. Collection efficiencies above 90% are verified for the particle range from 2-10 micron and typical gasifier particle distributions. The pressure loss can be as low as 3% and the purge flow can be adjusted to plant requirements. Purge flow secondary clean up is envisioned. The resulting clean purge gas can be utilized for plant operation or can be returned to the main flow.

In view of the successful completion of this program, there should be serious consideration given to future stationary and rotating application engineering utilizing the design methodology and test data herein reported.

R E F E R E N C E S

- (1) Linhardt, H. D., "Investigation of High Velocity Wedge Separator for Particle Removal in Coal Gasification Plants", Phase I Report, DOE Contract EF-77-C-02-2709, January 31, 1978, UC-90C/ACD-38391-U
- (2) Dving, P. R., et al, "Particle Trajectories in Turbine Cascades", American Institute of Aeronautics and Astronautics, Journal of Energy, Volume 3, No. 3, May-June 1979, Pages 161-166.
- (3) Meyer, J. P.; Edwards, M.S., "A Survey of Processes for High Temperature-High Pressure Gas Purification" Oak Ridge National Laboratory Report ORNL/TM-6178, November 1978