DESIGN CONSIDERATIONS: HIGH TEMPERATURE EQUIPMENT AND PIPING OF FLUID BED DRYER AND INCINERATOR VOLUME REDUCTION SYSTEMS

Narendra C. Papaiya, P.E.
Senior Nuclear Engineer

Leon V. Stanisz
Senior Mechanical Engineer

Burns and Roe, Inc.
633 Industrial Avenue
Paramus, NJ 07652

ABSTRACT

Recently the nuclear industry has started designing the facilities to reduce the volume of low level waste. Design considerations such as operation, arrangement/layout and analyses, pertaining to the volume reduction systems' high temperature equipment and piping must be addressed for the awareness of the nuclear industry.

The volume reduction systems which utilize the fluid bed dryer and the incinerator have high temperature components. The operating temperature of these components ranges from about 900°F(482.2°C) to 1600°F (871.1°C). The radwaste systems designed in the past for the PWR/BWR nuclear power plants have never utilized high temperature components (900°F to 1600°F, 482.2°C to 871.1°C).

In addition to the high temperature consideration, the operational/functional requirements impose stringent restrictions for the arrangement/layout of the volume reduction systems high temperature equipment and piping. The operational/functional considerations require that the proximate locations of the high temperature equipment is essential and the pipe routing to be short and direct with practically no flexibility. Because of this reason, the analyses of piping becomes more critical, requiring the selection of expansion joints, in order to reduce thermal stresses and equipment nozzle loading to acceptable levels.

With the design restrictions described above, this paper provides an understanding of the following:

(1) Operational/functional requirements to establish arrangement/layout of equipment and piping

(2) Arrangement/layout of equipment and piping

(3) Analyses of piping

INTRODUCTION

Fluidized Bed Volume Reduction Systems

The volume reduction systems (VR) use different technologies, one of which is fluidized bed technology. The VR systems using this technology are being offered by Aerojet Conversion Company (AECC) and Newport News Industrial Corporation (NNIC).

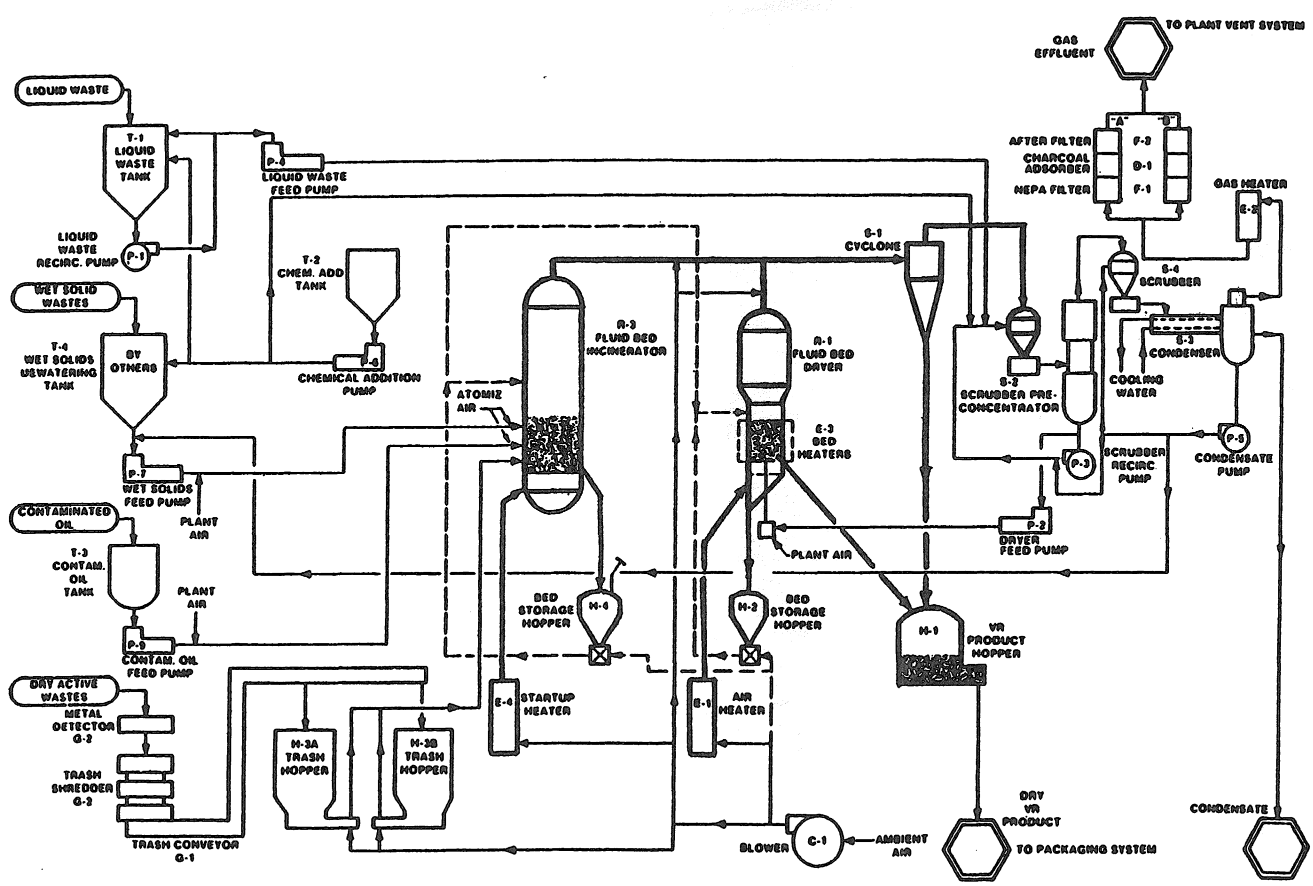
The fluidized bed VR systems offered by AECC are: (1) Combined fluid bed dryer/incinerator system, (2) Stand-alone fluid bed incinerator system. The combined fluid bed dryer/incinerator system is capable of handling dry active waste (DAW), concentrates, spent regenerates, resins and filter sludges. The stand-alone incinerator system is capable of handling dry active waste (DAW), resins and filter sludges. The fluidized bed VR system offered by NNIC is capable of handling dry active waste (DAW), concentrates, spent regenerates, resins and filter sludges.

The process vessels for the AECC VR systems are the fluid bed dryer and the fluid bed incinerator. The fluid bed dryer and the incinerator operate at temperatures of 900°F (482.2°C) and 1300°F (704.4°C) respectively. The NNIC VR system has a single process vessel which operates at 900°F (482.2°C) and 1600°F (871.1°C) for the drying and incineration mode of operation, respectively. Also other components associated with these process vessels, including piping are operational at high temperature of 900°F (482.2°C) to 1400°F (704.4°C).

AECC Combined Volume Reduction System

The AECC combined fluid bed dryer/incinerator system is used as a typical example in this paper to address design considerations such as operation, arrangement/layout and analyses, pertaining to high temperature equipment and piping. The selection of AECC VR system as the example is primarily due to Burns and Roe experience with their system and also due to the availability of the only AECC fluidized bed VR system. The operational/functional requirements of this equipment/piping is described for establishing the arrangement/layout.

Based on the operational/functional requirements, the equipment arrangement and piping layout has been established, The critical piping criteria and parameters are discussed in the analysis section.



▬ High Temperature Equipment and Piping

Fig. 1 - AECC Combined Fluid Bed Dryer/Incinerator Volume Reduction System

HIGH TEMPERATURE CONSIDERATION

As mentioned earlier, the major process equipment and associated piping of the typical AECC VR system are operational at high temperature (900°F to 1300°F, 482.2°C to 704.4°C) and low pressure (< 15 psig, 204.4 kPa). A typical AECC VR system flow schematic (Fig. 2) highlights the portion of these components. The design and operating temperatures pertaining to these components is provided in Table I.

The high temperature piping with adequate flexibility reduces the thermal stresses and nozzle loads on the equipment. However, the AECC VR system operational/functional considerations require that the equipment should be located proximately and piping should be direct.

TABLE I

Component	Design Temp.	Operating Temp.
(1) Equipment:		
R-1	1400°F (760°C)	900°F (482.2°C)
R-3	1500°F (815.6°C)	1300°F (704.4°C)
S-1, S-2, H-1, H-2 & H-4	1000°F (537.8°C)	900°F (482.2°C)
E-1 & E-4	1400°F (760°C)	900°F (482.2°C)
(2) Piping:		
S-1 to S-2	1000°F (760°C)	900°F (482.2°C)
S-1 to H-1	"	"
R-1 to H-1	"	"
R-1 to H-2	"	"
E-1 to R-1	"	"
R-3 to H-4	1400°F (760°C)	1300°F (704.4°C)
E-4 to R-3	1200°F (648.9°C)	1150°F (621.1°C)
R-1 & R-3 to S-1	1400°F (760°C)	1300°F (704.4°C)

OPERATIONAL/FUNCTIONAL REQUIREMENTS TO ESTABLISH ARRANGEMENT/LAYOUT OF EQUIPMENT AND PIPING

The high temperature equipment and piping of AECC dryer/incinerator system required specific arrangement to meet operational and functional requirements. These requirements establish relative and also proximate locations of the equipment. Following are the operational and functional requirements pertaining to specific high temperature equipment and piping.

Product Storage Hopper (H-1)

- The hopper (H-1) receives dry salt/ash by gravity, from the fluid bed dryer (R-1) and the incinerator (dry waste processor) (R-3) via gas solid/separator (cyclone) (S-1) during the drying and incineration mode of operation.
- In the event that maintenance would be required on the dryer (R-1), the bed material would be transferred by gravity to H-1.
- The hopper (H-1) is the equipment of the VR system which interfaces with the solidification system. The transfer of the dried product from H-1 would be performed by a product conveyor (R-4) to the solidification system for immobilization.

Bed Storage Hopper (H-2)

- The bed storage hopper (H-2) receives the bed material from R-1 by gravity. The bed material is stored in H-2 when the VR system is to be shutdown for extended periods of time.
- The bed material is pneumatically transferred from H-2 to R-1 prior to startup of the fluid bed dryer system.

Bed Storage Hopper (H-4)

The preceding requirements of H-2 apply to H-4 for the fluid bed incinerator (R-3).

Fluid Bed Dryer (R-1)

- The overhead offgas stream from the R-1 passes through a gas/solid separator (S-1) where the majority of the fines are removed from the offgas stream and discharged to the H-1 by gravity.
- Same requirement of second paragraph under "Product Storage Hopper (H-1)" also applies.

Fluid Bed Incinerator (Dry Waste Processor) (R-3)

The overhead offgas stream from R-3 passes through a gas/solid separator (S-1) where much of the ash is removed from the offgas stream and dropped to H-1 by gravity.

Gas/Solid Separator (Cyclone) (S-1)

The function of S-1 is to remove the majority fines from R-1 and the ash from R-3 for the discharge to H-1 and thereby clean the offgas stream. The offgas stream from S-1 enters S-2.

Air Heater (E-1)

The air heater (E-1) supplies heated air to R-1 for fluidizing the bed particles during the fluid bed drying mode of operation. To keep the heated air temperature closely uniform, the heat loss from E-1 to R-1 should be minimized.

Startup Heater (E-4)

The preceding requirement for E-1 applies to E-4 for the initial startup of R-3.

Venturi Scrubber/Preconcentrator (S-2)

The heat losses of the hot exhaust gases leaving S-1 and entering the venturi scrubber/preconcentrator (S-2) should be minimized. The reason being that the sensible heat of the gas stream from S-1 is utilized to preconcentrate the incoming waste feed in S-2.

Piping

- The free flow characteristic of the VR system product requires that (a) the angle of response should be 30° - 45° or less, (b) straight leg with minimum number of bends and fittings.
- The through the off gas and air lines heat losses are minimized by routing the pipe short and direct. The air lines have no restrictions for number of fittings, elbows and bends.
- The product build up and line plugs points are eliminated by (a) routing the pipe short and direct, (b) using angle of response of 30° - 45° or less (c) minimizing bends and fittings.
- During the drying and incineration mode of operation, the piping is designed to absorb the thermal expansion movements related to the high temperature of equipment and piping.

HIGH TEMPERATURE EQUIPMENT ARRANGEMENT

The typical arrangement of the AECC high temperature equipment in a facility is shown in Fig. 2 through Fig. 5. The arrangement of this equipment was developed, considering the operational and functional requirements of this equipment described earlier. The arrangement drawings were developed to the scale for the following plans and elevation:

Fig. 2 - Plan El. 0'-0" (0.00M)
Fig. 3 - Plan El. 25'-0" (7.62M)
Fig. 4 - Plan El. 45'-0" (13.72M)
Fig. 5 - Section View A-A

Fig. 2 - Plan El. 0'-0" (0.00M)

- A dry salt drumming station is located to the left of the hopper (H-1) to receive the dry product from H-1 via the product conveyor R-4.
- The location of the product storage hopper (H-1) provides the dry product and bed material receiving path relative to the gas/solids separator (S-1) and the fluid bed dryer (R-1). H-1 is located under S-1 and R-1 to receive product by the gravity. Also the location of H-1 close to the dry salt drumming station provides the shortest path for the dry product discharge.

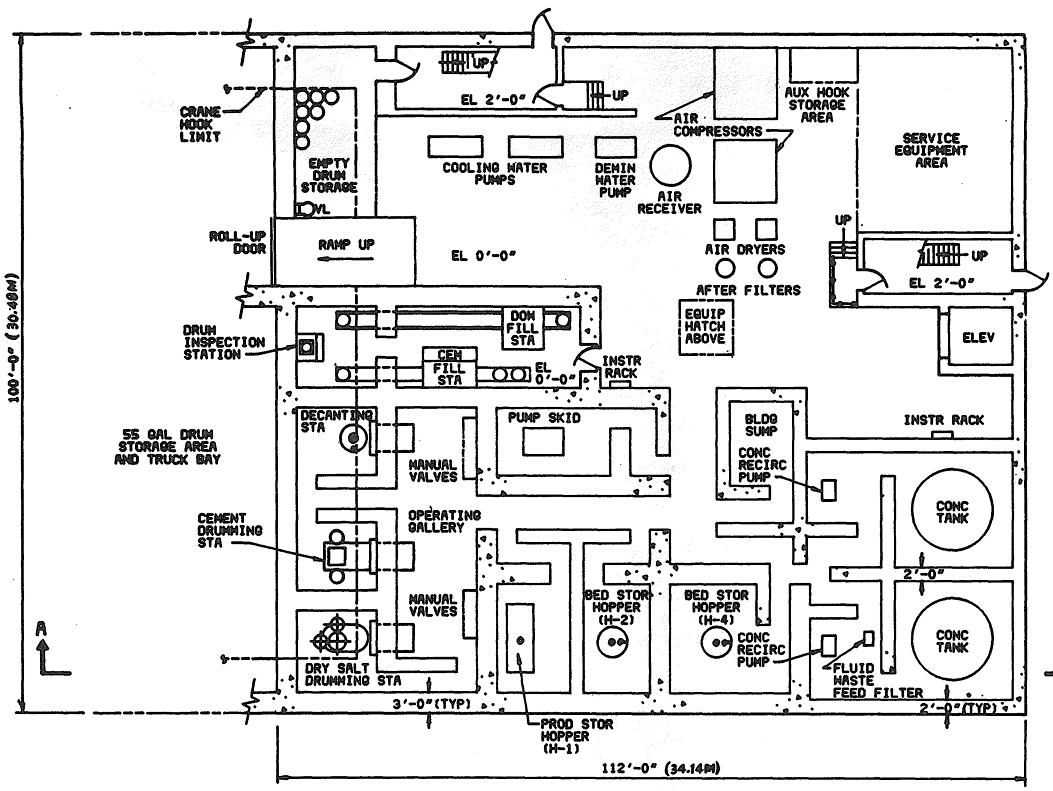


Fig. 2 - Plan El. 0'-0" (0.00M)

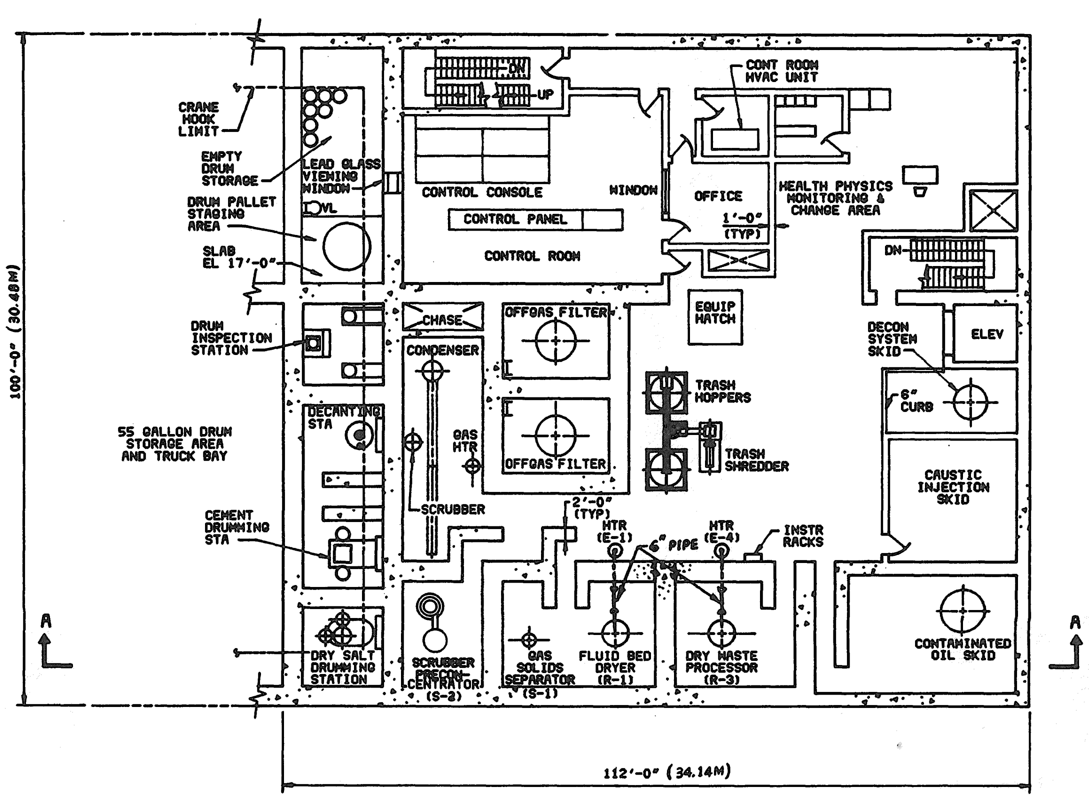


Fig. 3 - Plan El. 25'-0" (7.62M)

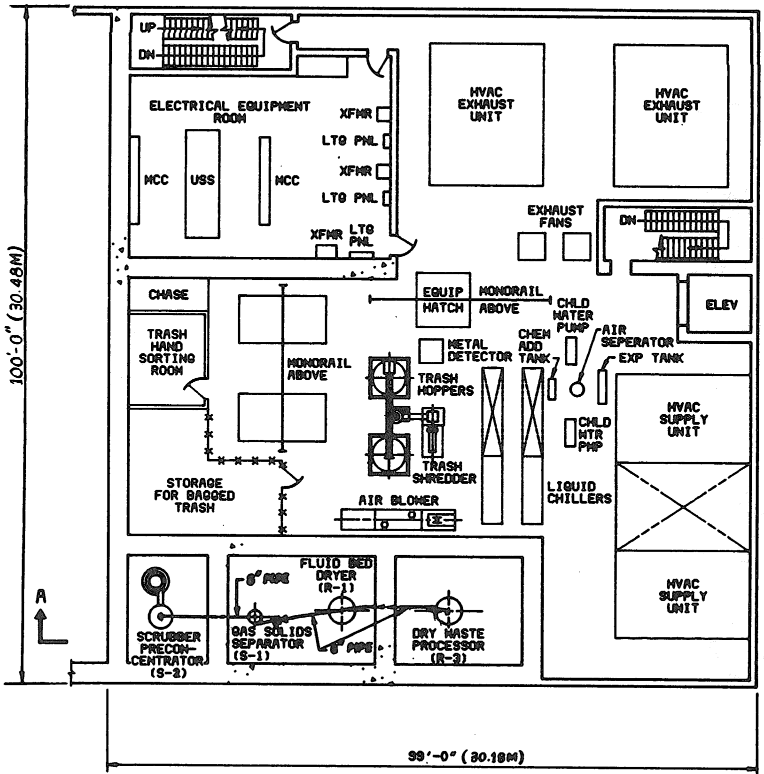


Fig. 4 - Plan El. 45'-0" (13.72M)

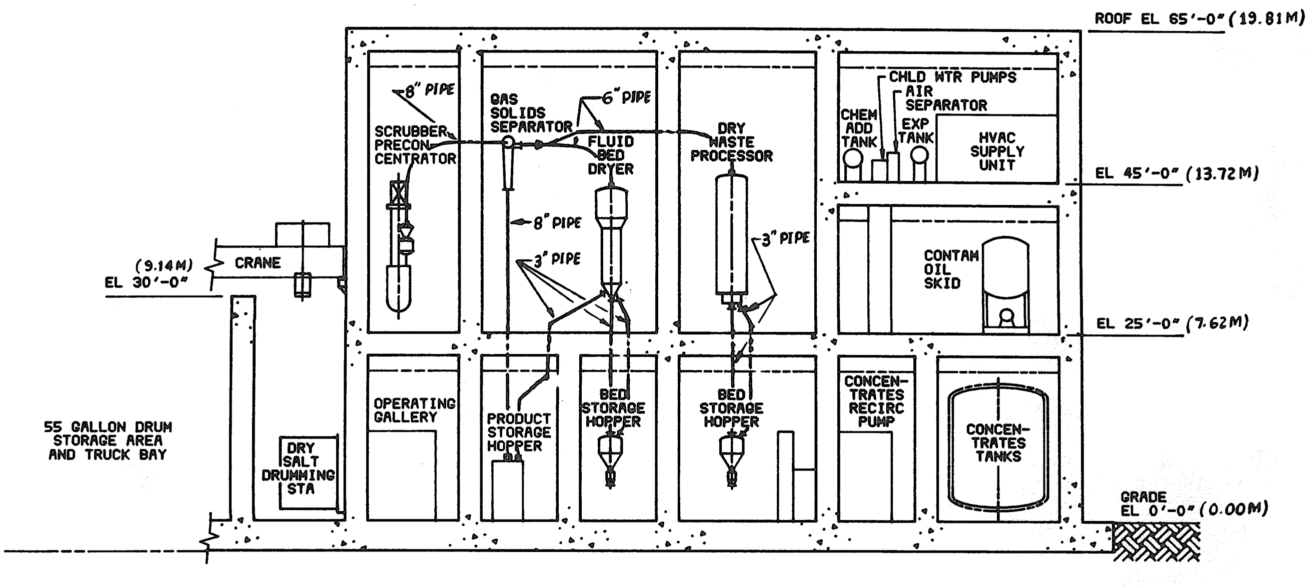


Fig. 5 - Section View A-A

- The bed storage hoppers (H-2 & H-4) are located to the right of the hopper (H-1). H-2 and H-4 are located under R-1 and R-3 respectively to receive the bed material by the gravity during maintenance.

Fig. 3 - Plan El. 25'-0" (7.62M)

- The gas/solids separator (S-1), the fluid bed dryer (R-1), the incinerator (R-3) and the Venturi scrubber/preconcentrator (S-3) are located to the right of the dry salt drumming station. The locations of R-1 and R-3 provide the straight flow path for the common offgas stream to S-1 and also for the bed material discharge by the gravity to the bed storage hoppers (H-2 & H-4). The location of S-1 above H-1 provides straight path for the dry product discharge by the gravity to H-1. Also it provides the shortest path for the offgas stream from R-1 and R-3. The location of S-2 provides the shortest and straight path for the off gas relative to S-1 to minimize heat losses.

- The heaters E-1 and E-4 are located outside the shield wall of R-1 and R-3. These heaters are located in the clean area of the facility and also close to R-1 and R-3 to minimize heat losses.

Fig. 4 - Plan El. 45'-0" (13.72M)

The equipment shown on the plan el. 25'-0" (7.62M) extend through this floor with the exception of the heaters (E-1 & E-4).

Fig. 5 - Section View A-A

The sectional view shows the relative locations of the equipment at different floor elevations.

HIGH TEMPERATURE PIPING LAYOUT

The layout of the major high temperature piping is described below, with the use of Fig. 2 through Fig. 5. The layout of the piping was developed considering the equipment nozzle locations and the restrictirons and the requirements of the piping described earlier.

- Piping from S-1 to S-2: The off gas piping (8") as shown on Fig. 3 and Fig. 5 was routed horizontally straight to penetrate the S-2 cubicle and then, vertically downward with one 90° bend.

- Piping from S-1 to H-1: The dry product discharge piping (8") as shown on Fig. 5 was routed vertically downward. The vertical drop also appears on the Fig. 2 and Fig. 3.

- Piping from R-1 to H-1: The bed discharge piping (3") as shown on Fig. 6 was routed vertically downward with three 45° bends to increase the slope.

- Piping from R-1 to H-2: a) The bed discharge piping (3") as shown on Fig. 5 was routed vertically downward, b) The windbox discharge piping (3") as whown on Fig. 5 was routed vertically downward with two 30° bends to increase the slope. The piping also appears on Fig. 2.

- Piping from R-3 to H-4: Same preceding layout from R-1 to H-2 applies for the piping from R-3 to H-4.

- Piping from E-1 to R-1: the hot air piping (6") as shown on Fig. 3 was routed to penetrate the R-1 cubicle and then dropped vertically downward along the shield wall. Since this is air piping, there were no restrictions for the number of fittings bends and elbows.

- Piping from E-4 to R-1: The hot air piping (6") as shown on Fig. 3 was routed to penetrate the R-3 cubicle and then dropped vertically downward along the shield wall. Since this is air piping, there were no restrictions for the number of fittings bends and elbows.

- Piping from R-1 & R-3 to S-1: The off gas piping (6") from the off gas nozzles of R-1 and R-3 came out vertically with a 90° bend to make a horizontal turn toward S-1. The horizontal piping from R-1 was routed to match the off gas inlet nozzle of S-1. The horizontal piping from R-3 was routed to penetrate the R-1 cubicle, using a 7° bend first and then a 17° bend to line up with the horizontal piping from R-1. A 30° lateral was used to connect the horizontal piping from R-3 to the horizontal piping from R-1, because of the difference in relative elevations. The layout is shown on Fig. 4 and Fig. 5.

HIGH TEMPERATURE PIPING ANALYSES

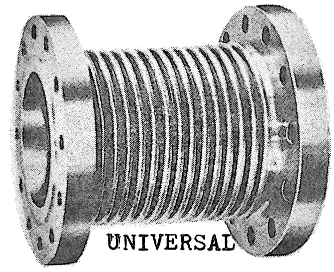
Piping Material and Temperature Requirements

One of the most important factors to consider in selecting steels for elevated temperature service is environment. The temperature and stresses to which the steel is being subjected and the media to which it is being exposed are extremely important factors and consideration must be given not only to the normal operating temperatures but also to the maximum temperature that may result (design temperature).

The austenitic stainless steels selected for this specific use are essentially alloys of iron, chromium, and nickel. These steels as a class are the strongest steels for service above 1000°F (537.8°C). Types 316, 316L, 321 and 347 stainless steels have excellent resistance to corrosion and oxidation and can be used for high-strength service up to about 1500°F (815.6°C).

Pipe Routing and Flexibility

The operational and functional design requirements of the volume reduction system, require the pipe routing to be short and direct with a minimum number of fittings and bends. These system limitations have created a unique condition, since as the metal temperature of the pipe or vessel increases or decreases, its length also varies due to thermal expansion or contraction. Therefore, unless compensation is provided for these dimensional changes, excessive thermal stresses will be induced on the piping or vessel and large forces and moments will be transmitted through the system to the equipment nozzles.



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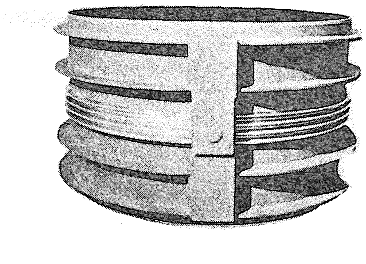

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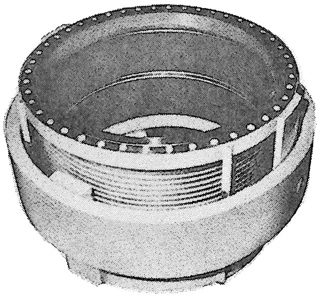

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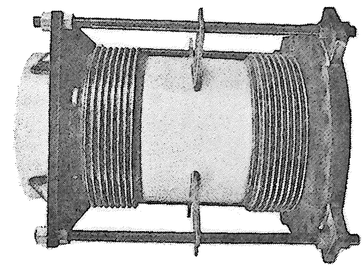

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Fig. 6 - Typical Expansion Joints

An experienced pipe designer would normally route the piping in such a manner as to allow adequate flexibility, which in turn would keep the thermal stresses within the code allowables while at the same time reducing the thermal loading on the equipment nozzles to a minimum. Since this is contrary to the system operational requirements, expansion joints are usually required.

Expansion Joints and Equipment Nozzle Loads

An expansion joint is a device containing one or more bellows to absorb dimensional changes, such as those caused by thermal expansion or contraction in a pipe line. Because of the low design pressure (<15 psig, 204.8 kPa) of the equipment, vessel wall thicknesses are typically in the 1/4" (0.635 cm) range. As previously stated, expansion joints are usually required because the high temperatures would create large deflections due to thermal expansion of the piping and vessels, which would result in high stresses and equipment nozzle loads.

The convoluted portion of an expansion joint is the bellows which is designed to flex when thermal movements occur in the piping system. The amount of movement the bellows must accommodate determines the number of convolutions required. Since bellows are unique, there are many design considerations which must be evaluated. The convoluted element must be strong enough circumferentially to withstand the line pressure of the system (which in this case less than 15 psig, 204.8 kPa), while also being responsive enough longitudinally to flex.

Some typical expansion joints are shown in Fig. 6.

Allowable Thermal Stresses

Since the incineration process operates at higher temperatures (above 1200°F, 648.9°C) than those for which allowable stress valves are assigned in ANSI B31.1 Power Piping Code, the question arises whether the allowable stress valves listed in the ASME Boiler and Pressure Vessel Code, Section I, for the austenitic stainless steels at temperatures over 1200°F to 1500°F could be used for the design of stainless steel pipe under ANSI B31.1 This question has been presented to the ASME B31.1 Section Committee on Power Piping for clarification. As of this date, no reply has been received, a satisfactory reply is anticipated.

CLOSING COMMENTS

The paper provides an understanding of the AECC high temperature equipment and piping. The arrangement/layout of the equipment and piping is only related to the operational/functional and high temperature considerations. The analyses of the piping also provides an understanding of the considerations involved, rather than detailed calculations.

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NOMENCLATURE

R-1 = Fluid Bed Dryer
S-1 = Gas Solid Separ ator (or Cyclone)
H-1 = Product Storage Hopper
H-2 = Bed Storage Hopper for the Fluid Bed/Dryer
H-4 = Bed Storage Hopper for the Fluid Bed Incinerator
R-3 = Fluid Bed Inciner- ator or Dry Waste Processor
S-2 = Venturi Scrubber/ Preconcentrator
E-1 = Fluid Bed Dryer Air Heater
E-4 = Incinerator Startup Heater
R-4 = Product Conveyor