DOE/PC/90279-- T18

ADVANCED COAL-FUELED COMBUSTOR FOR RESIDENTIAL SPACE HEATING APPLICATIONS

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1.0 INTRODUCTION

The objective of this program is to develop an integrated combustor/heat exchanger which burns coal either as a slurry or as a dry ultrafine coal and which is suitable for use in a range of residential space heaters.

The objective will be accomplished in two phases. During the current, initial phase combustor concepts will be developed, fabricated, and evaluated. Upon successful optimization of the advanced coal-fueled combustor, the project would proceed to a second phase to integrate the combustor into a prototype space heater to be demonstrated. The first phase of the program includes the following tasks:

Task 1. Combustor Design Definition
Task 2. Combustors for Slurries
Task 3. Combustors for Dry Ultrafine Coals
Task 4. Performance Verification
Task 5. Reporting

This quarterly report describes the work performed during the period from February 1, 1987 to April 30, 1987. The entire effort focused on Task 1, combustor design definition, in particular, the combustor design concepts.

A more detailed review of Task 1 can be found in the Topical Report, "Combustor Design Definition," June 1987, which was prepared under this contract.

2.0 COMBUSTOR DESIGN DEFINITION

The purpose of this task is to establish the performance and application requirements for a 100,000 Btu/hr coal-fueled combustor which can be used in a residential space heating furnace and to develop a series of design concepts to satisfy these requirements.

In developing the combustor design, various design parameters were considered, along with their impacts on combustor performance. These design parameters included combustor size, burner type/configuration, wall temperature/material of construction, atomizer type (for coal-liquid mixtures), pilot flame size, excess air level, and air preheat temperature.

Using carbon burnout models developed at EER, it was determined that a residence time of one second would be adequate for 99% carbon combustion efficiency. This residence time corresponds to a combustor volume of roughly 2 ft^3, which is well within the size limit for a domestic heater. The one second residence time assumes a top coal particle size of 40 μm (dry ultrafine coal) and, for coal-liquid mixtures, a droplet size of under 500 μm. It also assumes that large coal agglomerates do not form from the droplets.

Two types of flame stabilization techniques were judged most appropriate for a domestic combustor: swirl and radiant quarl. Other stabilization techniques which were considered but rejected included bluff body, jet differential velocity, and opposed jets.

Swirl is generated by either tangential entry of air or the use of guide vanes. The swirling air causes an adverse axial pressure gradient which results in reverse flow and recirculation of hot gases. Mixing of hot gases with fuel and air stabilizes the flame. The refractory quarl design has been used at EER in several tunnel furnaces fired at 70,000 to 100,000 Btu/hr. This design, which uses a divergent mixing chamber stabilized by radiation from the hot refractory, has proven to be reliable for stabilizing flames.

Two approaches to the design of the combustion chamber itself were considered, an air cooled steel shell and a refractory lined or ceramic coated chamber. Heat transfer calculations were made to determine if a double-walled combustor using a jacket of cooling air surrounding the combustion chamber was feasible. The conclusion was that this approach is feasible but that experimental testing would be necessary to assure that the wall temperature could be maintained at satisfactory levels, e.g., 1200-1400°F for a steel shell.

An atomizer for coal-liquid mixtures will be obtained from a commercial supplier, if possible. Otherwise, EER will modify an existing atomizer or design a new unit. An air-assist atomizer will probably be required. The spray will be characterized to ensure that the pattern is compatible with the combustor geometry and that the drop size distribution is satisfactory.

A natural gas or propane pilot will be used for startup and coal ignition. A typical startup sequence will be (a) spark ignition of gas pilot, (b) heatup with gas, (c) introduction of coal, (d) shutdown of pilot when combustor has reached a temperature sufficient for a stable coal flame.

Excess air levels of 30-50% should ensure adequate carbon burnout without producing unreasonable stack heat losses. Air preheat levels up to about 600°F will be used in the combustion tests.

3.0 COMBUSTOR DESIGN CONCEPTS

A combustor design review meeting was held on April 9, 1987 at EER's Orrville, Ohio office. Attending this review were representatives from EER, the Will-Burt Company, and DOE. Three combustor concepts were presented and discussed. The three designs included:

- swirl burner with air-cooled combustion chamber shell,
- radiant quarl burner with ceramic-coated air-cooled shell, and
- film-cooled, gas turbine-like combustor.

3.1 Air-Jacketed Swirl Combustor

The air-jacketed combustor shown in Figure 3-1 utilizes a conventional swirl-stabilized pulverized coal burner. The burner incorporates a short refractory lined diverging quarl with a central coal nozzle. The coal nozzle will itself have a diverging outer dimension so that when moved axially will vary the area, and thus velocity, of the secondary air. The flame will be stabilized with a set of radial swirl vanes producing a theoretical swirl number of about 1.0. The combustor shell will be formed from stainless steel and cooled with an air jacket through which circulating air flows to maintain the temperature of the inner stainless steel shell to acceptable levels, about 1400°F or less. The circulating air is the air which is used for space heating. An approximate flow rate for a 100,000 Btu/hr heater would be 1000 ft^3/min. The temperature rise of the air in passing through the shell would be roughly 50°F, e.g., 70° air would be heated to 120°F. The space between the inner and outer shells would probably be set by circulating air pressure drop considerations. That is, the air passage must be large enough so that the required flowrate can be supplied by an inexpensive fan or blower.

3.2 Radiant Quarl Combustor

The radiant quarl combustor, as shown in Figure 3-2, uses an axial flow burner and a long (~1 ft) radiant refractory quarl to stabilize the flame.

The ceramic-coated metal inner wall can operate at higher temperatures, up to about 1900°F, than an unprotected stainless steel wall. Heat transfer calculations predict that the inner wall temperature can be maintained below 1900°F with air cooling.

The advantage of a radiant quarl stabilized axial flow burner vs. a swirl burner is that the former is less likely to result in ash and slag deposition on the combustor walls. Furthermore, introduction of tertiary air at the downstream end of the quarl should also help to minimize ash deposition. The principal questions which need to be answered by experimentation are whether flame stabilization can be achieved with this design and whether the refractory quarl and wall coating are sufficiently durable for long-term, reliable, domestic use.

3.3 Film-Cooled Combustor

The film-cooled combustor, shown in Figure 3-3, makes use of cooling methods common to those used in gas-turbine technology. As in the previous two combustion chamber designs, the film-cooled combustor also has an air-cooled metal inner wall. However, there are two important differences vs. the other designs: (1) cooling air flows through small holes in the inner wall, where it also sweeps along the wall providing cooling and minimizing ash deposition, and (2) the combustion air is staged, with the burner stoichiometry being fuel rich (SR = 0.70, where SR, stoichiometric ratio = fraction of stoichiometric air). There are several potential advantages of staging the combustion air. These advantages include improved flame stabilization at the burner, more uniform heat release over the length of the combustion chamber resulting in lower peak temperatures, and lower NO_x emissions. This combustor can be represented by a well-mixed stirred reactor zone (i.e., the swirl burner), followed by a long plug-flow zone. The series combination of well-mixed and plug flow reactors provides the vigorous mixing which helps flame stabilization followed by a much less intensely mixed zone to promote complete burnout.

Another configuration of film-cooled combustor is also under consideration. This is a design which uses narrow concentric slits instead of holes to admit cooling air.

A transpiration-cooled combustor is also a possibility. This design uses a perforated metal inner wall cooled by air flow through the wall. The perforations are very small, e.g. 50-100 μm, and large in number. Transpiration cooling can be very effective for reducing heat transfer to the combustor wall; however, its use will depend on the availability of a suitable perforated metal and the flow rate of cooling air which would be required to reduce wall temperature to the required level.

4.0 FUTURE WORK

The next steps are to screen burner configurations based on the swirl and axial flow burners discussed above, fabricate several combustion chambers, and evaluate at least three burner/combustion chamber combinations. The key performance criteria will be ignition and flame stability, combustion efficiency, emissions, and the amount of ash/slag deposition on the combustor walls.

Existing EER coal burners in the 100,000 Btu/hr capacity range will be modified as necessary by employing different combinations of basic burner type (i.e., swirl or axial flow), coal injectors, and refractory quarl designs. The burners will be screened in an existing combustion chamber,called the Turbulent Flame Reactor (TFR). The TFR is about the same size and shape as the actual combustor to be used for the residential heater; however, the TFR has water-cooled walls and will provide a severe test of each burner's ability to stabilize the coal flame and achieve satisfactory carbon burnout.

The best burners from the screening tests will then be evaluated in combustion chambers fabricated for this project. These include the air-cooled, double-wall designs (metal wall and ceramic coated), and a film-cooled design.

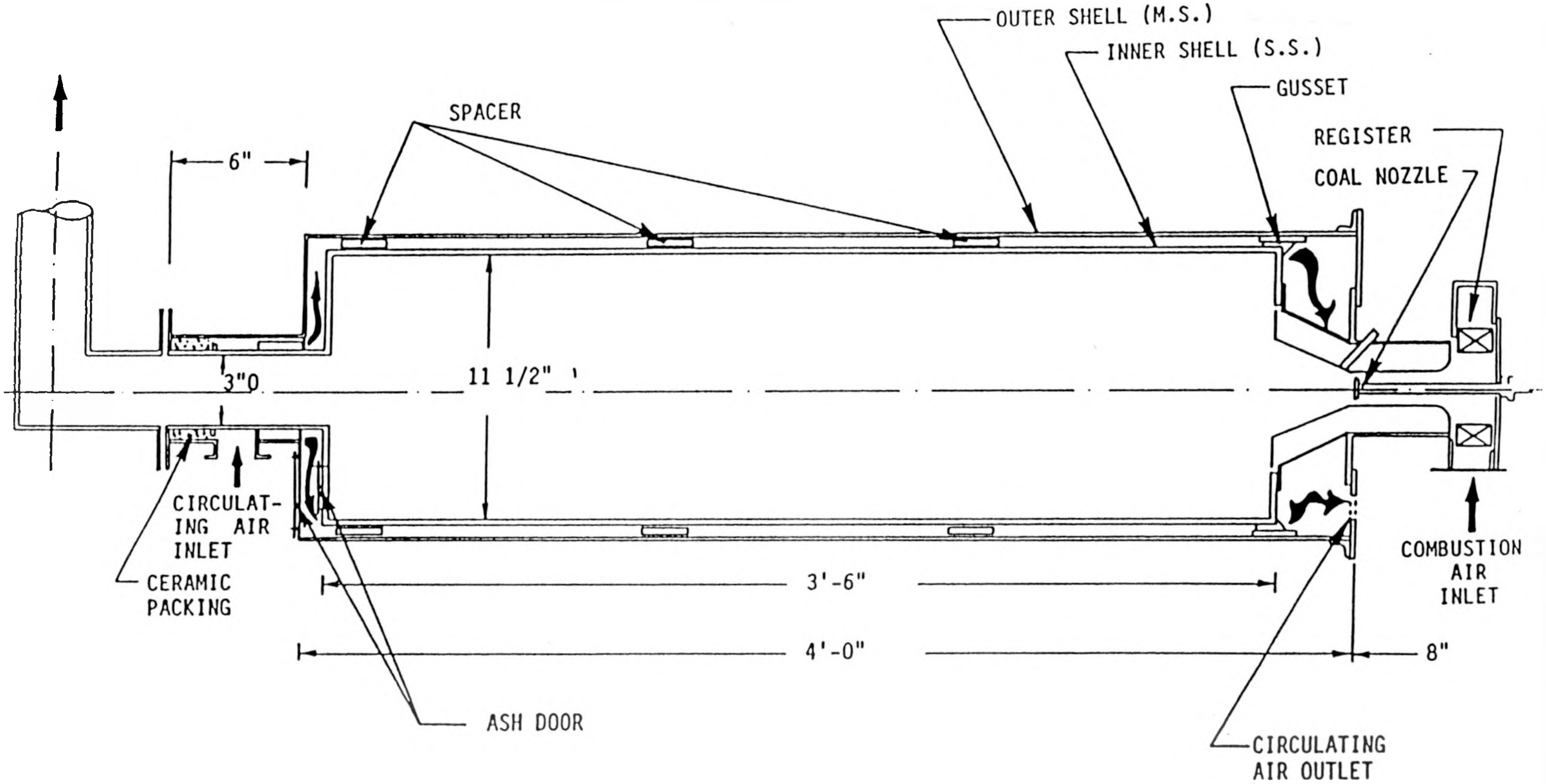

Figure 3-1. Air jacketed swirl combustor.

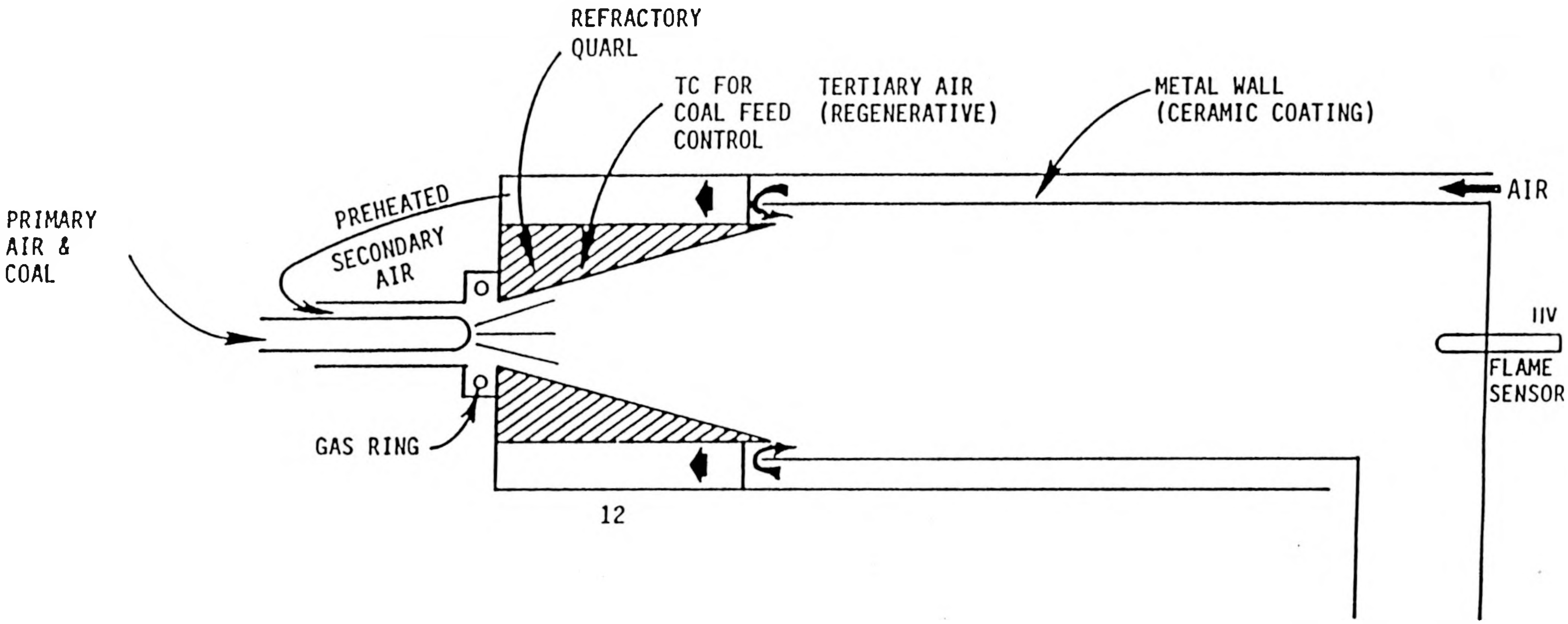

Figure 3-2. Radiant quarl combustor design.

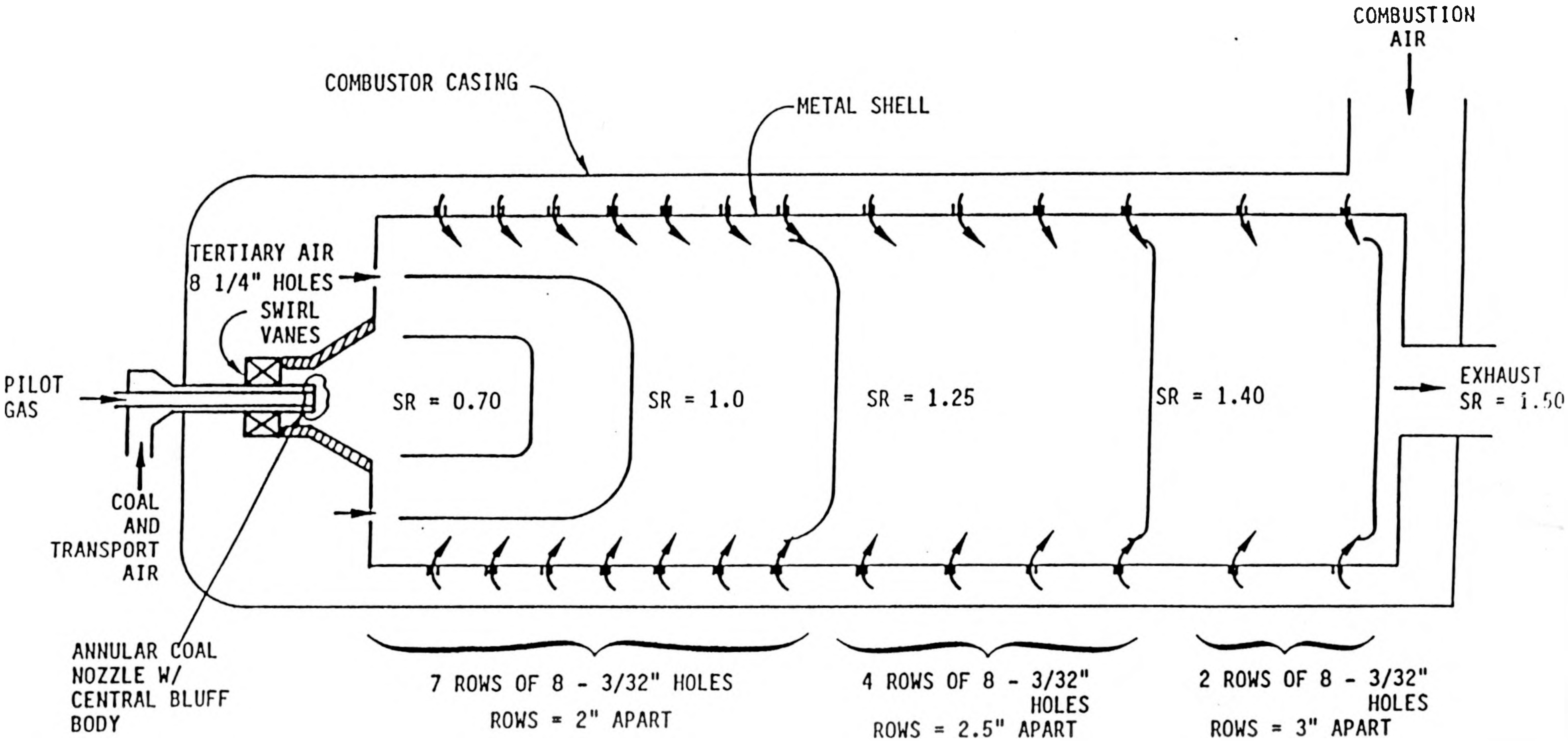

Figure 3-3. Film-cooled combustor.