CO_2 Capture by Moving Bed Temperature Swing Adsorption

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EXECUTIVE SUMMARY

An "end-of-pipe" process has been developed to capture carbon dioxide (CO_2) from flue gas from coal-burning power plants, cement plants, and the like. It will treat flue gas immediately after the fly ash is removed. The presence of minor amounts of fly ash, however, should not pose a serious problem. The process employs temperature swing adsorption (TSA). It uses solid adsorbent to take-up CO_2 from flue gas. And it uses the heat contained in the flue gas to drive-off the enriched CO_2 from the adsorbent. The keys to performance are: the flue gas temperature and the CO_2 concentration, which are equivalent to *the available heat* and *the required heat*, respectively. Together, they dictate whether the heat contained in the flue gas is sufficient to drive the separation. When they are properly balanced, the need for parasitic energy is minimal. In contrast, the conventional alternative means for CO_2 capture is scrubbing, which requires about 30% of the gross output of a power plant's steam in order to regenerate the scrubbing solution. Hence, the need for parasitic energy is enormous when scrubbing is used.

The ARI TSA CO_2 capture process has been evaluated via experiments and computer simulations. They revealed important parameters, e.g, the amount of adsorbent required and the size of the equipment, which represent the majority of the capital cost. The ARI TSA process tests showed that both high CO_2 purity (99%) and high recovery (89%) were possible. Additional tests with CO_2, H_2O, and SO_2 in a simulated flue gas showed no signs of adsorbent breakdown. A patent application has been filed (20060230930), and a PCT application (Publication No.=WO 2006/112977) was submitted.

Adsorbent attrition is of minimal concern on account of features that allow less breakage and friction than for other moving bed designs, and a device by which adsorbent fines (if they occur) can be continuously removed.

The design is modular, i.e., the system will be comprised of dozens of identical parallel units. Each one could be amenable to shut-down for maintenance, without adversely affecting the processing capacity of the remainder. If sufficient redundancy is provided for, plant operation and output should not be impacted.

Now that preliminary testing and engineering are complete, we plan to build a pilot-scale TSA process (1 ton of CO_2 per day) to evaluate the process under realistic conditions. The project is being organized by ADA-ES, based in Littleton, Colorado. These tests will yield engineering data and will assess its technical and economic feasibility. The cost for testing will be partly covered by a DOE grant that was recently announced, along with industrial contributions, and will require about 2 years.

PROCESS DESCRIPTION

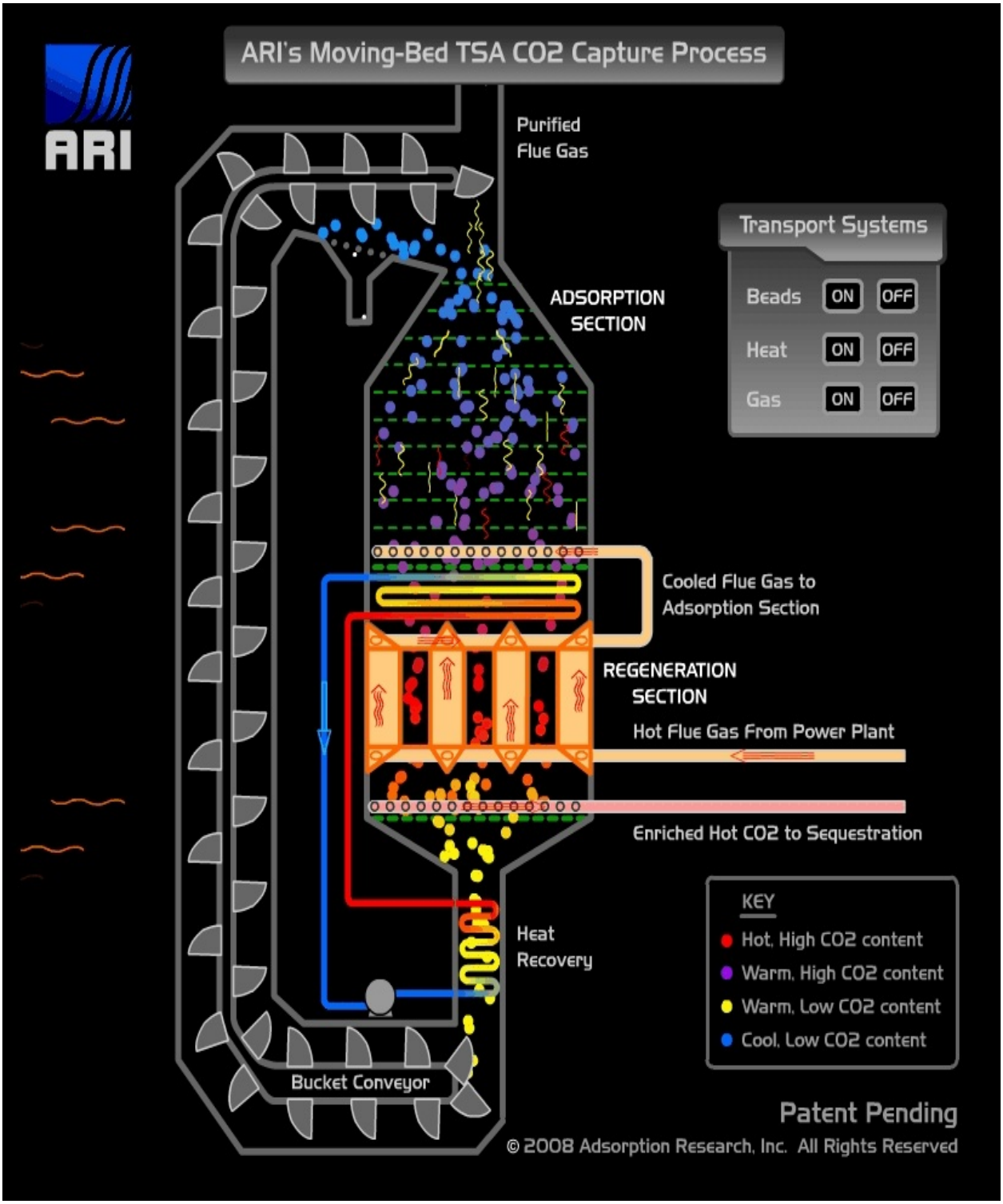
The process is illustrated below. This diagram was taken from an animated version. As such, it represents a specific instant of its operation, during which the adsorbent, gas, bucket conveyor, and a heat-transfer medium are all moving.

Let's start with the adsorbent beads, being delivered to the top of the adsorption section by the bucket conveyor. At this point the beads (blue) are cool, and relatively free of CO_2. As the beads pass over a screen, any fines that may have been generated (white dots) during adsorption or regeneration are separated. The whole beads fall onto a series of perforated trays. The perforated trays are designed to retard the beads, so that their residence time in the adsorption section is a few minutes. While in the adsorption section, the beads contact flue gas, consisting of adsorbable components such as CO_2 (shown as red squiggles) and non-adsorbable components such as nitrogen (shown as yellow squiggles). Flue gas enters the adsorption section through the perforated distributor pipe at the bottom of that section. The adsorbable components are taken-up the adsorbent as they pass countercurrently, and the non-adsorbable components escape through the stack at the top.

Upon reaching the bottom of the adsorption section, the adsorbent beads are fully loaded, and they proceed to the regeneration section. First, the beads are preheated, as they pass through a countercurrent heat exchanger. In that section, the beads pick-up heat, which is recycled from beads in the heat-recovery section. (The latter beads are hot and relatively free of CO_2.) The beads then contact a heat exchanger section in which the hot flue gas delivers its heat to the beads. Now the beads are red. As can be seen, the hot flue gas enters this heat exchanger section from the power plant, in a duct (at the right-hand side). The flue gas and adsorbent bead remain separated by the heat exchange surface, which is just a metal barrier. The diagram shows the flue gas in a rectangular duct, with triangular sections at the bottom and top, respectively, through which the hot flue gas is delivered and the relatively cool flue gas collected. (The relatively cool flue gas may subsequently be quenched in a separate vessel – not shown.) That relatively cool flue gas is then introduced to the adsorption section through the perforated distributor pipe mentioned earlier. The hot beads readily desorb the CO_2 and any other adsorbable components, and their color changes to yellow. Meanwhile, the enriched CO_2 is collected and withdrawn in a perforated pipe, to sequestration.

As mentioned earlier, the hot adsorbent beads, depleted of CO_2 are cooled by the circulating fluid in the heat recovery section. Afterwards, the cooled beads fall into buckets of the conveyor and are lifted back to the top of the adsorption section. As they are lifted, additional cooling occurs, indicated byt the brown horizontal squiggles, which emanate from the bucket conveyor enclosure, at the left.

A Key identifies the states of the adsorbent beads according to colors at various locations. The block labeled "Transport Systems" refers to animation features, which obviously are all "on" in the snapshot. Those allow one to view the various aspects individually, or in pairs, and to appreciate the relative motion and synchronization, which of course is not possible with a still image.


ARI's Moving-Bed TSA CO2 Capture Process
ARI
Purified
Flue Gas
Transport Systems
Beads ON OFF
Heat ON OFF
Gas ON OFF
ADSORPTION
SECTION
Cooled Flue Gas to
Adsorption Section
REGENERATION
SECTION
Hot Flue Gas From Power Plant
Enriched Hot CO2 to Sequestration
Heat
Recovery
Bucket Conveyor
KEY
Hot, High CO2 content
Warm, High CO2 content
Warm, Low CO2 content
Cool, Low CO2 content
Patent Pending
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Justification

The laboratory data and computer simulations were used to generate approximate capital and operating cost estimates of a commercial CO_2 recovery system. In addition, budgetary quotes were obtained from vendors to arrive at an overall plant cost estimate. The main design parameters and results are shown in Table 1.

Table 1. Operating and Capital Costs for CO_2 Capture by the ARI TSA Process at a 500 MW Coal Fired Power Plant.

Flue Gas Flow Rate:	=	1,500,000 SCFM = 2,200 MMSCFD
CO_2 Emission Rate	=	15,000 tons per day
Flue Gas CO_2 Concentration	=	12% (vol) from the plant
Flue Gas H_2O Concentration	=	12% (vol) from the plant
Outlet Gas CO_2 Concentration	=	1.20% (vol) from the TSA system
Min. CO_2 Recovery Percentage	=	92%
Max. Exhaust Gas Pressure Drop	=	<5 in. H_2O in the TSA system
Adsorbent Reservoir	=	10,000,000 lb
Temperatures		
Flue Gas Inlet Temp.	=	500°F
Outlet Gas Temp.	=	125°F
Adsorbent Regeneration Temp.	=	350°F
Dimensions		
Approximate Footprint and Height	=	300 ft x 200 ft x 50 ft.
Estimated Cost		
Fabricated Steel	=	$147 million
Initial Adsorbent Inventory	=	$ 10 million
Building & Foundation	=	$ 3 million
Installation + Contingency	=	$262 million
Approximate Capital Cost	=	$420 million.
Amortization (6% x 15 yr)	=	$ 43 million per year
Power Cost	=	$ 7 million per year
Total Processing Cost*	=	$9.65 per ton of CO_2

* Assuming the system is on-line 95% of the time, i.e., 347 days per year.

As can be seen, the estimated capital cost includes the structural steel and adsorbent, as well as the building, foundation, installation labor, and contingency. The resulting operating cost per ton of CO_2 captured will depend on the accuracy of these estimates, as well as the amortization rate and term. This is the cost for the captured CO_2, at 1 atm, without drying (which we expect to cost less than an extra $1 per ton).