

How shockwaves can cut the energy penalty

An update on the now patented CEFCO multi-pollutant control and carbon capture technology, which promises considerable energy efficiency through its use of power plant "spent" steam in aerodynamically designed reactors to promote pollutant capture processes. A pilot scale system is in operation at a Peerless Mfg Co facility in Wichita Falls, Texas.

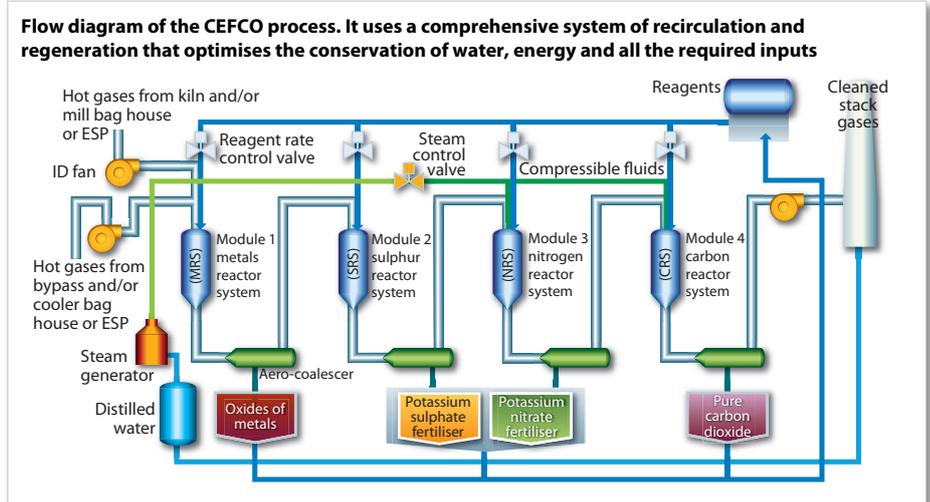
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The CEFCO (Clean Energy and Fuel Company) process, described in the October 2010 issue of *Modern Power Systems* ("Sending shockwaves through the multi-pollutant control business"), is targeted towards industries such as coal-fired power generation, cement and petrochemicals. Since the publication of that article the US Patent and Trademark Office issued a patent certificate covering the process to CEFCO Global Clean Energy (US 7842264B2, 30 November, 2010, *Process and apparatus for carbon capture and elimination of multi-pollutants in flue gas from hydrocarbon fuel sources and recovery of multiple by-products*).

The CEFCO process is a combined carbon capture and multi-pollutant control technology capable of capturing trace metals (including mercury), fine particulates (including those with sizes smaller than 2.5 microns), SO_x, NO_x and carbon dioxide. The process is designed to meet or exceed compliance with the EPA's MACT (Maximum Achievable Control Technology), NESHAPs (New Emissions Standards for Hazardous Air Pollutants) and interstate transport rule requirements (which limits air pollutants from being carried (transported) to states downwind of the polluter). When future GHG (greenhouse gas) or carbon rules are established, CEFCO will also offer compliance with those.

Using shockwaves

The CEFCO process comprises multiple aerodynamically-shaped reactors and aerodynamic coalescers (gas/liquid separators) in series for sequential pollutant



separation and removal. Each reactor system is designed to remove one of the targeted groups of pollutants, and the steps are repeated in sequence for the remaining pollutants. CEFCO believes that its process will remove virtually all (99+%) of the pollutants and at least 90% of the carbon dioxide.

The process is based on highly efficient "molecular surface chemistry" employing proprietary aerodynamic reactor technology. The flue gas being treated is kept moving very rapidly, with short residence times in each reactor system.

A key concept of the CEFCO process is that steam is injected through aerodynamic nozzles and exits at Mach speeds, generating supersonic shock waves, resulting in the

formation of sub-atmospheric and adiabatic reaction zones in each reactor module. The concept is referred to in the EPA and Department of Energy literature as well as in the MACT standards themselves variously as a "hydro-sonic", "free-jet collision", "collision scrubber", or "supersonic collision" process.

Each targeted group of pollutants intimately collides with and mixes with very fine fast moving liquid droplets of the appropriate absorbing or adsorbing reagent. The pollutants are captured and encapsulated by the liquid droplets (and reacted with the reagent). The droplets then are "grown" to a physical size sufficiently large to permit separation by a flow separating aero-coalescer.

The capture and mass transfer mechanisms are detailed in the published patent, referred to above. Briefly, the sub-atmospheric and adiabatic reaction zone enables the occurrence of endothermic-then-exothermic chemical reactions that capture the pollutant and then form the desired end-product within seconds.* Since the chemical reactions occur simultaneously in the multiplicity of small droplets which are repeatedly contacted and re-combined, the reactions are completed extremely rapidly – in contrast to the

The CEFCO process in brief

With conventional thermo-chemistry, the chemical reactions required for capturing pollutants from flue gas, including carbon dioxide, require the addition of expensive heat, pressure and catalyst, incurring what is commonly referred to in the power industry as the "energy penalty". The essence of the CEFCO process is to use shockwaves generated by "spent" or "post-power-production" steam (from the steam return loop of the power plant) in aerodynamic reactors as a low cost substitute, thereby minimising any "energy penalty".

* Readers are welcome to contact the authors to discuss the application of Hess's Law and its effect.

traditional bulk chemistry reactions in conventional pollution control processes, which rely on much longer residence times for proper contact with absorbents, catalysts and adsorbents.

CEFCO describes the mechanism employed in its process as "molecular surface chemistry" because the fine droplets have a large ratio of surface area to mass, making it possible for the rapid chemical reactions to take place.

There are no further additions of chemicals or complex/metal catalysts required in the process, which serves to simplify the chemistry as well as to significantly reduce overall capital and operating costs. The shockwave performs all the requisite functions in terms of energy, pressure and catalyst.

Overview of the equipment

The complete CEFCO process comprises a series of four reactor modules, for the sequential capture of all four groups of air emissions: the metals reactor system (MRS) for trace metals and particulates; the sulphur reactor system (SRS) for SO_x ; the nitrogen reactor system (NRS) for NO_x ; and the carbon reactor system (CRS) for CO_2 . Each of the systems includes subsequent processing of the captured pollutants into marketable end-products.

Since the CEFCO process is designed to be installed in modules, it is possible for users (who may already have various "conventional" pollution control technologies installed in their plants, such as FGD, SCR, or baghouses plus activated carbon injection for mercury removal) to retain their sunken investments, but to install some of the CEFCO modules in conjunction with existing systems. The CEFCO technology is flexible and capable of accommodating such situations.

A flow diagram of the CEFCO process is shown on p 24.

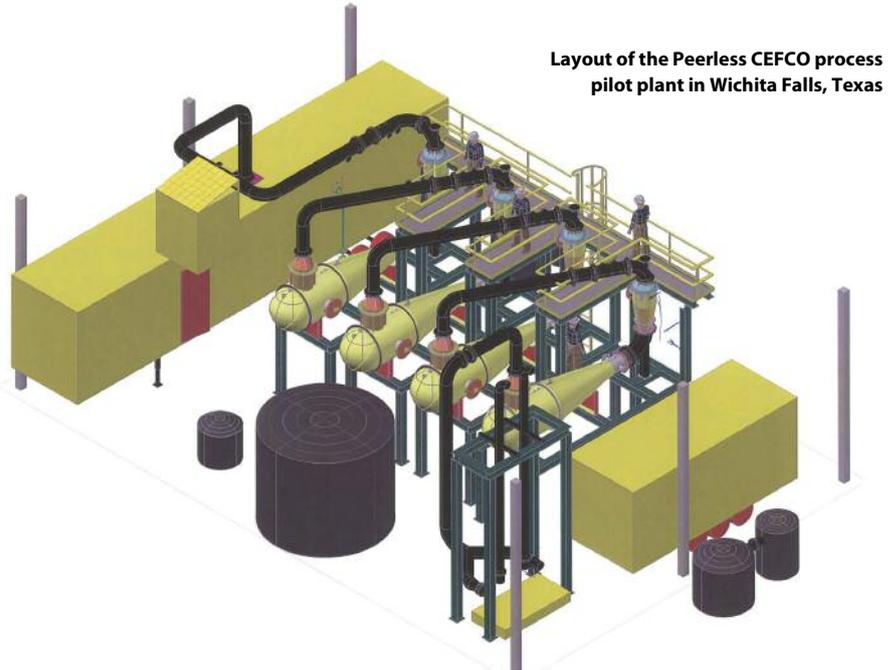
The system is designed to achieve multi-pollutant capture plus carbon capture with a total energy penalty of less than 10%.

The CEFCO process makes use of post-power-generation "waste steam" that is returning via the return loop to be condensed. The shockwave is generated by channeling this spent steam through aerodynamically designed supersonic nozzles into a sub-atmospheric and adiabatic zone of the reactor at such energy and pressure that no other heat, pressure or catalyst are needed – as already noted.

Again as already mentioned, all reactions take place within seconds so the equipment footprints and volumes are very small in comparison to other technologies.

The source of heat applied to liberate the purified CO_2 in the CRS module is a slipstream of the same spent steam (from the return loop of the steam on its way to be condensed).**

The mass transfer, capture mechanisms and chemical reagents applicable in each module of the CEFCO process, as well as the co-production of potassium sulphate and potassium nitrate fertilisers as end-products are described in detail in the published patent, and were also touched on in the previous article in *MPS* (October 2010).



Layout of the Peerless CEFCO process pilot plant in Wichita Falls, Texas

Typically a hydroxide solution (such as KOH) and/or a carbonate solution (such as K_2CO_3) would be used in the respective modules for capturing SO_x , NO_x and CO_2 and converting them into useful and saleable end-products. By using such a combination of reagents, it is anticipated that some CO_2 will be captured in the SRS module and further CO_2 will be captured in the NRS module, thus lessening the overall load for 90%-plus carbon capture in the CRS module.

The CEFCO process is able to maintain the selectivity of capturing each group of pollutants by manipulating the five parameters of the process: residence time; velocity; temperature; pressure; and pH in each reactor module. These parameters represent the intersection of physics and chemistry with the concept of reaction kinetics.

The final exit gas is cleaned of all metals, particulates, sulphur, NO_x and carbon, leaving only pure O_2 , N_2 , noble gases, and water vapour. The next step would be separation out of the valuable industrial gases (by a company specialising in harvesting such gases). The final exit stack would only have to be of normal industrial building code height. No more tall stacks would be required in the future for power plant complexes.

In the spring of 2011, CEFCO and Peerless Manufacturing Co (the licensed manufacturer of the CEFCO process equipment for the USA) established a 1-3 MW equivalent pilot plant at a Peerless factory in Wichita Falls, Texas.

In recent months, systematic parametric testing has been in progress and certain steps are being developed at the request of several power producers and cement producers.

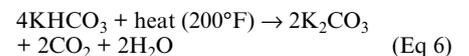
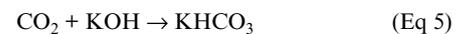
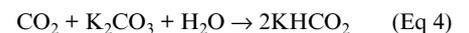
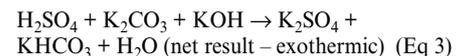
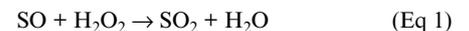
The basic chemistry and process development

As originally patented, the CEFCO process uses alkaline reagents that are both for

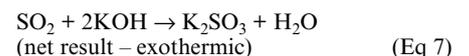
capturing the SO_x and the NO_x , as well as the CO_2 , and converting each of them into useful end-products.

The use of a combination of K_2CO_3 and KOH injected into the shockwave reactor modules is proposed as a complete replacement for all the current chilled amine, ammonia and designer-amine scrubber solutions, and other systems being proposed for carbon capture.

By way of example the following equations show the chemical reactions typically occurring inside the sulphur reactor system module:



(The carbon dioxide is liberated as a purified gas, and can be compressed and transported for disposal, etc. The K_2CO_3 is continually regenerated in a cyclic process. The process is also a net generator of water, liberating H_2O previously trapped in fossil fuels.)



These processes work with NaOH + Na_2CO_3 , as well as with KOH + K_2CO_3 . The co-inventors of CEFCO have studied and worked with NaOH + Na_2CO_3 , as well as with KOH + K_2CO_3 , for the past 30 years, and have specified them in the published patent.

** The CEFCO system is potentially a very energy-efficient air pollution control technology. Carbon capture could be turned into part of an economic process for producing alternative fuels when used in conjunction with technologies such as coal-to-liquids and gas-to-liquid. The potassium sulphate and potassium nitrate fertilisers produced by the process could also be used to promote large scale agricultural algae production for, say, biodiesel production. The "new water" liberated from fossil fuels could be used for irrigation purposes. The trace metals captured could be sold to metal refiners for industrial purposes.

In developing and demonstrating the process to the US power industry in mid-2011, it was requested by certain US power producers that the carbon capture ability of the SRS and NRS modules be minimised to reduce the operating costs and complexities of dealing with carbon dioxide, leaving carbon capture to be performed in a CRS module, the last module in the flow scheme, if and when it is required.

CEFCO responded successfully in the case of the SRS test module by using only the KOH reaction, represented by Equation 7 above, forcing the SO₂ capture + product-forming reaction to take place within the supersonic-shockwave-generated sub-atmospheric-adiabatic zone. Thus the steps shown in Equations 2 to 6 were circumvented and yet a fertiliser product was still produced, consisting of potassium sulphite-sulphate.

The SRS module at the Wichita Falls test facility is currently being operated in this way, consuming just the KOH required on a stoichiometric molar basis to achieve the 99+% SO₂ capture and conversion into potassium sulphite fertiliser in the most cost-effective way. Carbon capture is minimised by not using any K₂CO₃ as capture reagent in the SRS reaction process. This achieves a substantial reduction in OPEX. But the end-product is still a saleable and valuable fertiliser, K₂SO₃ (eventually oxidising to K₂SO₄).

CEFCO's parametric testing of the modules continues at Wichita Falls, and CEFCO is



Photograph of the Peerless CEFCO process pilot plant in Wichita Falls, with two of the five co-inventors, Donald Degling (left) and Robert Tang (right)

working to improve cost-effectiveness. The next task, as requested by the power industry, will be to modify operation of the NRS module to maximise NO_x capture and minimise carbon dioxide capture, while producing KNO₃ fertiliser.

Progress on this will be reported in the future. CEFCO is also working towards a system which provides full compliance with the current MACT, NESHAPs and interstate transport rules, and with likely future GHG and carbon rules.

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