CEFCO PROCESS: EXPLANATION OF AERO-REACTOR CHEMICAL REACTION LISTING + PROCESS PARAMETERS + MASS TRANSFER MECHANISM

(April 27, 2010)

From the composition of the hydrocarbon-fueled (including all fossil-sourced) flue gas, CEFCO, or "Clean Energy Fuel Company" identified four (4) main groups of contaminants based on their physical and chemical properties: (1) metals and fine particulates; (2) sulfurous gases such as SOx; (3) nitrous gases such as NOx; and (4) carbonaceous gases such as CO_2. The CEFCO process is designed to treat and capture these contaminants in separate aerodynamic reaction chambers and extract them in separate aerodynamic coalescers in a system to be described as a Module:

A) Metals Reactor System ("MRS" — Module 1);

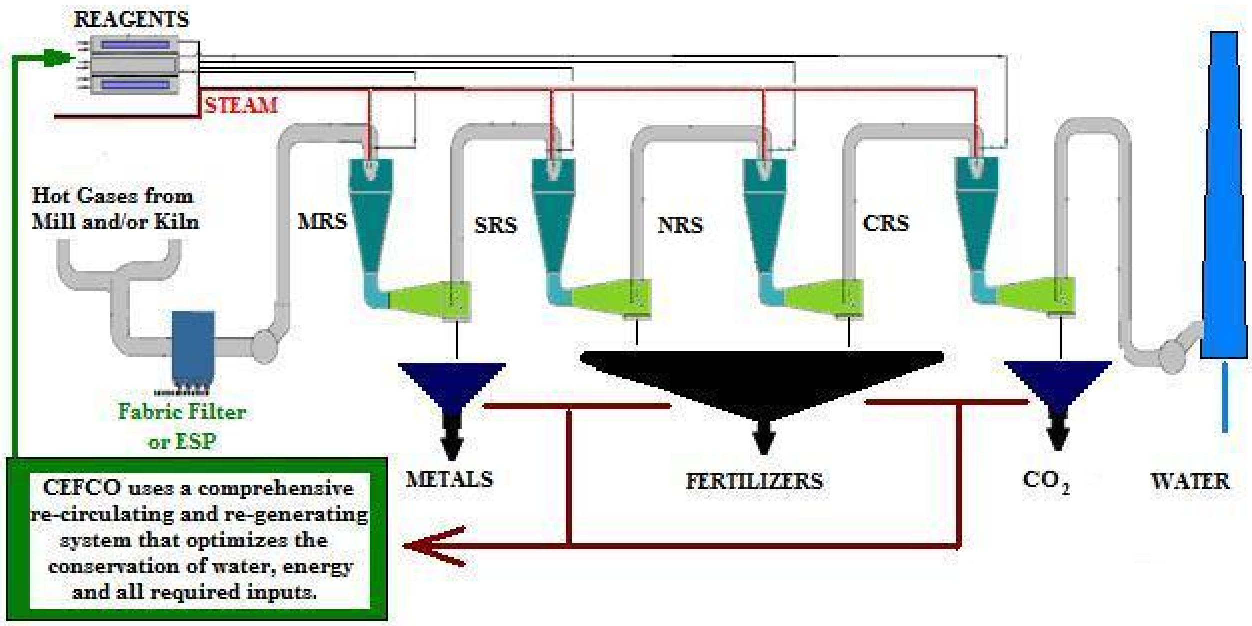
B) Sulfur Reactor System ("SRS" — Module 2);

C) Nitrogen Reactor System ("NRS" — Module 3); and

D) Carbon Reactor System ("CRS" — Module 4).

Each aerodynamic reaction chamber and system (herein called a "Module") has unique dimensions and characteristics that are proprietary know-how. The logic is explained below.

Exhibit 1: CEFCO Process Modules Diagram (in a sample configuration)



A key concept in the CEFCO Process is that, at all times, the flue gases being treated move rapidly through the aerodynamic system. In physics, the "dwell-time" or "residence-time" for

each select-target reaction is governed by the speed of the flue gas traveling through the respective distances of the sequential reaction zones within the appropriately designed reactor system. Except for the "residence-time" of just over 1 second for the very stable carbon dioxide 99% reaction, the reaction zone "residence-times" for all other targeted contaminants are significantly under 1 second.

All of the targeted reactions within the aerodynamic zones are governed by at least five (5) major and well-studied parameters: Time, Velocity, Temperature, Pressure and pH, which will assist in the "selective reaction" and, therefore, "selective removal" under designed conditions. The Time or Velocity can be governed by regulating the speed and length of travel of the targeted flue gas component within the respective reaction zones. The same aerodynamic mechanism is used to remove each group of targeted emissions as well as Carbon Dioxide, by varying the "target-selection parameters" and the select-chemical reagents used. There is no need to add extra catalyst. Based on empirical data from previous work of the physicists, the reactions occurring at and immediately downstream of the free jet nozzles within the reactors are extremely quick. With a typical and nominal flue gas at a post-ESP or post-baghouse Temperature of 300°F to 400°F and traveling at a velocity between 50 and 80 ft/sec., the flue gas will enter and exit (via the stack) the entire CEFCO Process system including all four reactor systems in less than 6 seconds.

The Ewan aerodynamic mechanism uses moderate steam (between 400 °F to 700 °F, between 60 psi to 100 psi) to generate supersonic shock waves (intense energy and pressure waves) to cause massive and repetitive collisions of the targeted emissions' and the CEFCO Reagent's molecules, which then altogether exits into a subsonic free jet via a subsonic nozzle inside the aerodynamic reactor resulting in a sub-atmospheric condition showing extreme pressure drop, rapid temperature drop, the various selectively intended reactions, the planned velocity of the molecules traveling through the reaction zone, the rapid mass displacement, the endothermic-exothermic reactions of producing the intermediate and end-product, and then the pressure and heat recovery through the aerodynamic coalescer, etc. In theory and practice, the Ewan technology has induced a sudden and extreme collapse of (ΔT) Temperature and (ΔP) Pressure, plunging down from the "ultra-critical" range into the normal range within split-seconds. This plunge locks in the end-product of the reactions without expending or consuming an inordinate amount of energy, which is often called "parasitic load" in the energy industry. The Ewan aerodynamic mechanism is employing a branch of aerospace science, and not the traditional thermodynamics mechanism and chemistry as commonly used in the energy industry.

The reaction times presented in the following table were taken from the data observed by the physicists and in some of the available reports and recent calculations, and are representative of reactions occurring based on the Process Engineering provided design-conditions of the Pilot Test flue gas model entering the first reactor (MRS) inlet at: approximately 300°F, 13.5 psia and traveling at 50 to 60 ft./sec. (See: Table 1, below).

Table 1: CEFCO - Parameters for Targeted Reactions

Target	Time	Temp °F	pH	Module	Velocity-Distance
Metals and Fine Particulates	Over 99% completed < 0.01 sec	Zone Condition: 220°F - 160°F	6.0 - 7.0	MRS	Very short travel distance within System
SOx	Over 99% completed < 0.2 sec	Zone Condition: 180°F - 150°F	7.5 - 8.5	SRS	Short travel distance within System
NOx	Over 99% completed < 0.5 sec	Zone Condition: 135°F - 140°F	9.0 - 11.0	NRS	Longer travel distance within System
CO_2 COx	Over 90% completed ≤ 1.0 sec	Zone Condition: Ambient to 150°F	8.5 - 11.0	CRS	Longest travel distance within System

During the Pilot Test, unexpected changes to these parameters may occur. The Process Engineer will evaluate these actual conditions and adjust/modify as needed to obtain optimal results. <u>Objectives</u>: Will need to define the differential solubilities of the gases much more clearly in terms of absorption and reaction times, reaction rates, appropriate pH levels and temperature ranges. <u>Expectations</u>: Some CO_2 (to be measured in the Test) will be removed in the SRS, but the great majority will be removed in the NRS and CRS.

Table 2: Pressure and Temperature Expected to be Measured at Each Reactors System

KEY ITEMS:	MRS	SRS	NRS	CRS	Total System
Press. Drop (inches of w.c.)	2.0"	1.9"	1.8"	1.7"	7.4"
40% Pressure Recovery	0.8"	0.76"	0.72"	0.68"	2.96"
Net Pressure Drop:	1.2"	1.14"	1.08"	1.02"	4.44"
Net Press. Drop (psia):	0.043	0.041	0.039	0.037	0.123
Exit Pressure (psia)	13.45	13.42	13.38	13.34	13.34
Exit Temp (°F)	180°-200°	150°-170°	140°-160°	135-140°	135°-140°
Net Temp. Drop (°F)	100°-120°	30°	10°	5°-20°	160°-165°

<u>Notes:</u>

1. The net pressure drops were based on projections made by and later proven by Ewan.
2. The pressure drops indicated are representative of the pressure losses across the subsonic nozzle in each reactor. Other minor pressure losses will occur in the ductwork, on the order of less than 0.5 in. w.c. along each section of duct. These pressure losses are calculable.
3. The temperatures listed are based on historical empirical data and not based on calculation.

<u>Observations:</u> The "Exit Temp (°F)" after each reactor system is slightly higher than the "Zone Condition Temp (°F)" because of the occurrence of "40% Pressure Recovery". We will explain the Temperature Recovery and Pressure Recovery within the system via the aerodynamic designs.

The following steps are to be reviewed together with the Process Engineer's Process Diagrams.

A) Metals and Fine Particulates Removal — Description of MRS Steps

Metal Removal and Recovery Reactions

H_2O_2 solution is injected into the MRS as the primary select-reagent.

As a contingency , KCl solution is also available, as well as Cl_2 available — but may not be needed.

Mercury Compound Reactions with Peroxide [Main "Targeted Reactions"]

$Hg + 2OH^-_{\text{(reagent)}} \rightarrow HgO + H_2O$

$HgO + H_2O \rightarrow Hg(OH)_2$

Elemental Mercury Reactions with Chlorine (if used)

$Hg + Cl_2 \rightarrow HgCl_2$

$Hg + 2\,Cl^- \rightarrow HgCl_2$

Perry's Chemical Engineers Handbook shows the following data:

Mercury has a melting point of -38.9°C (about -40°F) and a boiling point of 361°C (681°F). Elemental Mercury is expected to occur as a liquid micro-droplet at the temperature range entering into the MRS.

Mercury Chloride has a melting point of 277°C (530°F) and a boiling point of 304°C (579°F). $HgCl_2$ is expected to occur as a solid at the temperature range within the MRS.

Mercury Chloride should also be encapsulated and removed with the liquids via the aero-coalescer. Elemental Mercury is expected to be encapsulated, "grown" larger and removed with the other liquid streams via the aero-coalescer. The aerodynamic mechanism and function will be proven to have performed the job successfully.

The Process Engineer has recommended to use the example of Barium metals for all Mass and Chemical Balance calculations as representative of all other metals within the flue gas for the sake of simplicity and the trace quantities of too many metals within the Pilot Test. Barium, according to the Perry's Chemical Engineer's Handbook, shows a Melting Point of 1,562°F. We expect to capture and remove Barium and Barium Compounds as solids. Process Engineer precautions, showing Barium (to represent symbolically for all other metals) reacting with all three KCl, Cl_2 and H_2O_2, are for insurance-purposes in a practical Pilot Plant exercise. The recommended reagent to be added is H_2O_2.

Table 3: Representative MRS Reactions

For H_2O_2 ➔	$H_2O_{2\,\text{(reagent)}} + Ba \rightarrow BaO + H_2O$

For KCl ➔	$2\ KCl + 2\ H_2O + Ba \rightarrow BaCl_2 + 2\ KOH + H_2$
For Cl_2 ➔	$Cl_2 + Ba \rightarrow BaCl_2$

As a possible result of the Pilot Test, CEFCO believes that we will find that it is unnecessary to add any chlorine or chloride chemical to the MRS to capture metals (such as Mercury or Barium) or particulate matter (< 1 micron), all of which are either a solid or liquid, or possibly a condensable vapor. We expect that over 90% of all metals will be in the solid phase (and will be captured together with the particulates in the condensated liquid drops), and some metals (like Mercury) will be in the liquid phase (which also will be captured together in the condensed liquid drops). Other trace metals will be captured in the oxide form. All three groups will be captured and removed via the aero-coalescer in the exiting liquid stream.

[Separately, our patent-content text covers Uranium and Selenium removal, but they are not within the scope of this Pilot Test and Explanation.]

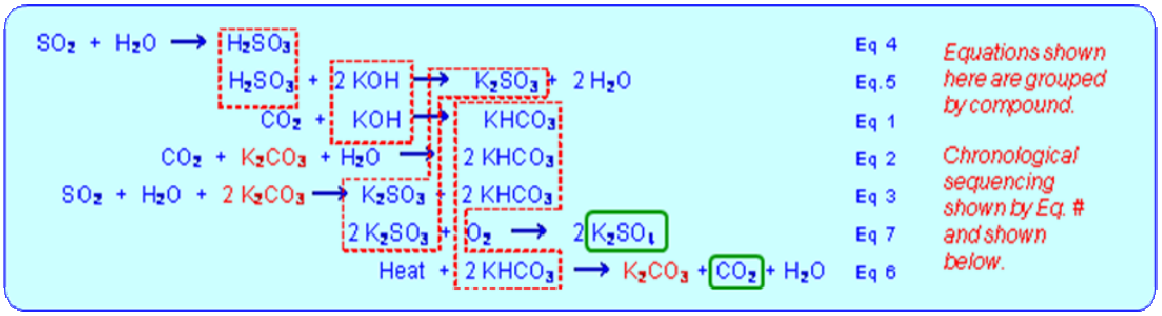
Metal Extraction Chemical Reactions

Metals + Inorganics + H_2O_2 → Oxidized Metals + Insoluble Ash
Metals + Inorganics + KCl → Metal Chlorides + Insoluble Ash

Metal Washing Treatment Reactions

Metals + Inorganics + Water → Metal Extract + Insoluble Ash
Metals + Inorganics + HCl (if added) → Metal Chlorides + Insoluble Ash

B) Sulfur Oxide Removal — Description of SRS Steps



Note 1a: K_2CO_3 (here this is the reagent being regenerated and re-circulated from the external regeneration tanks)

Reactions inside the SOx Aerodynamic Reactor and Aerodynamic Coalescer:

$SO_2 + H_2O \longrightarrow H_2SO_3$
$H_2SO_3 + 2\ KOH_{\text{(reagent)}} \longrightarrow K_2SO_3 + 2\ H_2O$ (Reaction Products)
$CO_2 + KOH_{\text{(reagent)}} \longrightarrow KHCO_3$ (Carbon Capture)
$CO_2 + K_2CO_{3\,\text{(reagent)}} + H_2O \longrightarrow 2\ KHCO_3$ (Carbon Capture)
$SO_2 + 2\ K_2CO_{3\,\text{(reagent)}} + H_2O \longrightarrow K_2SO_3 + 2\ KHCO_3$ (Reaction Products)

Conventional Reactions after leaving the Aerodynamic Coalescer:

$2\ K_2SO_3 + O_2\ \ (\text{or } H_2O_2) \longrightarrow 2\ K_2SO_4$

(Oxidation² — outside of Aero-Module)

$\text{Heat} + 2\ KHCO_3 \longrightarrow K_2CO_3\ _{\text{(regenerated)}} + CO_2\ _{\text{(liberated gas)}} + H_2O$

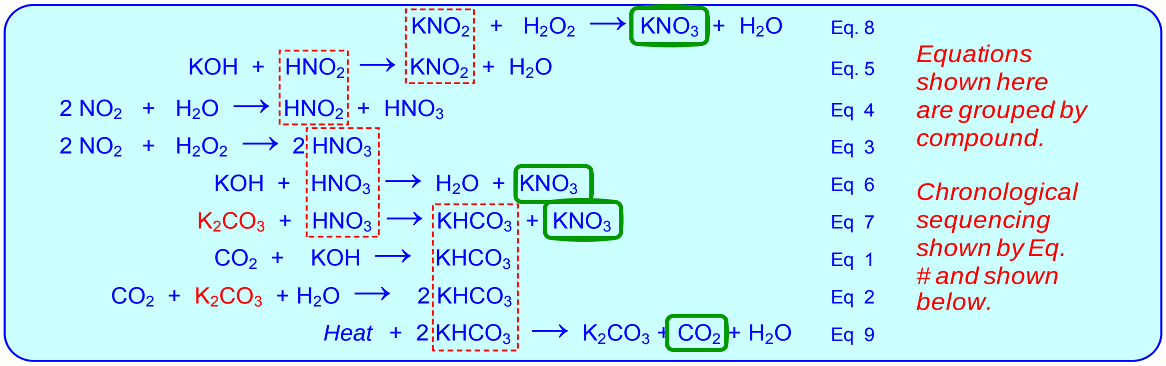
Note 1b: K_2CO_3 (here is being regenerated) re-generation process liberates CO_2 as a gas and produces a supply of recovered water for many subsequent uses.

Table 4: Theory of Ewan SRS Module — Sequence of Chemical Reactions and Thermodynamics (to be measured and refined) by Process Engineer.

Seq.	Reaction	Location	Notes
Carbon Capture — Inside of the Ewan Reactor with Reagent			
Eq. 1	$CO_2 + KOH \rightarrow KHCO_3$	SOx Reactor	Rapid reaction in transitional condition.
Eq. 2	$CO_2 + K_2CO_3 + H_2O \rightarrow 2\ KHCO_3$	SOx Reactor	Rapid reaction in transitional condition.
SO_2 Removal — Inside of the Ewan Reactor with Reagent			
Eq. 3	$SO_2 + H_2O + 2\ K_2CO_3 \rightarrow K_2SO_3 + 2\ KHCO_3$	SOx Reactor	Rapid reaction in transitional condition.
Eq. 4	$SO_2 + H_2O \rightarrow H_2SO_3$	SOx Reactor	Rapid reaction absorbing heat.
Eq. 5	$H_2SO_3 + 2\ KOH \rightarrow K_2SO_3 + 2\ H_2O$	SOx Reactor	Rapid reaction in transitional condition.
End Products — Outside of the Ewan Reactor, using the Cooper Chemistry			
Eq. 6	$\text{Heat} + 2\ KHCO_3 \rightarrow K_2CO_3 + CO_2 + H_2O$	Decarbonator	Captured CO_2 is liberated and stored. K_2CO_3 Reagent is regenerated.
Eq. 7	$2\ K_2SO_3 + O_2 \rightarrow 2\ K_2SO_4$	Oxidizer	Potassium Sulfate end product.

Notes:
1. K_2CO_3 is a regenerative reagent with regeneration occurring in the decarbonator as the captured CO_2 is stored.
2. KOH is added to the reagent mixture as a molar equivalent to the potassium removed as a reaction product.

C) Nitrogen Oxide Removal — Description of NRS Steps



$KNO_2 + H_2O_2 \longrightarrow \boxed{KNO_3} + H_2O$ Eq. 8

$KOH + HNO_2 \longrightarrow KNO_2 + H_2O$ Eq. 5

$2\ NO_2 + H_2O \longrightarrow HNO_2 + HNO_3$ Eq 4

$2\ NO_2 + H_2O_2 \longrightarrow 2\ HNO_3$ Eq 3

$KOH + HNO_3 \longrightarrow H_2O + \boxed{KNO_3}$ Eq 6

$K_2CO_3 + HNO_3 \longrightarrow KHCO_3 + \boxed{KNO_3}$ Eq 7

$CO_2 + KOH \longrightarrow KHCO_3$ Eq 1

$CO_2 + K_2CO_3 + H_2O \longrightarrow 2\ KHCO_3$ Eq 2

$\text{Heat} + 2\ KHCO_3 \longrightarrow K_2CO_3 + \boxed{CO_2} + H_2O$ Eq 9

Equations shown here are grouped by compound.

Chronological sequencing shown by Eq. # and shown below.

Note 1a: K_2CO_3 (here this is the reagent being regenerated and re-circulated from the external regeneration tanks)

Reactions inside the NOx/CO_2 Aerodynamic Reactors and Aerodynamic Coalescers:

$2\ NO_2 + H_2O \longrightarrow HNO_2 + HNO_3$

$2\ NO_2 + H_2O_2\ _{\text{(reagent)}} \longrightarrow 2\ HNO_3$

$KOH\ _{\text{(reagent)}} + HNO_3 \longrightarrow KNO_3 + H_2O$ **(Reaction Product)**

$HNO_3 + K_2CO_3\ _{\text{(reagent)}} \longrightarrow KNO_3 + KHCO_3$

(Reaction Product + Carbon Capture)

Possible Supplemental Reactions (to be tested and verified):

$KOH_{\text{(reagent)}} + HNO_2 \longrightarrow KNO_2 + H_2O$

$KNO_2 + H_2O_{2\,\text{(reagent)}} \longrightarrow KNO_3 + H_2O$ (Reaction Product)

See Note 2: "Oxidation".

Conventional Reactions after leaving the Aerodynamic Coalescer:

KNO_2 (if escaped un-oxidized) + $H_2O_{2\,\text{(reagent)}} \longrightarrow KNO_3 + H_2O$

(Oxidation[2] — outside of Module)

$\text{Heat} + 2\,KHCO_3 \longrightarrow K_2CO_{3\,\text{(regenerated)}} + CO_{2\,\text{(liberated gas)}} + H_2O$

Note 1b: K_2CO_3 (here is being regenerated) which re-generation process also liberates "pure" CO_2 as a gas and produces a supply of recovered water for many subsequent uses.

Table 5: Theory of Ewan NRS Module — Sequence of Chemical Reactions and Thermodynamics (to be measured and refined) by Process Engineer.

Seq.	Reaction	Location	Notes
Carbon Capture — Inside of the Ewan Reactor with Reagent			
Eq. 1	$CO_2 + KOH \rightarrow KHCO_3$	NOx Reactor	Rapid reaction in transitional condition.
Eq. 2	$CO_2 + K_2CO_3 + H_2O \rightarrow 2\,KHCO_3$	NOx Reactor	Rapid reaction in transitional condition.
NO_2 Removal — Inside of the Ewan Reactor with Reagent			
Eq. 3	$2\,NO_2 + H_2O_2 \rightarrow 2\,HNO_3$	NOx Reactor	Rapid reaction absorbing heat.
Eq. 4	$2\,NO_2 + H_2O \rightarrow HNO_2 + HNO_3$	NOx Reactor	Rapid reaction absorbing heat.
Eq. 5	$KOH + HNO_2 \rightarrow KNO_2 + H_2O$	NOx Reactor	Supplemental reaction.
Eq. 6	$KOH + HNO_3 \rightarrow H_2O + KNO_3$	NOx Reactor	Rapid reaction releasing heat. Generates some end product.
Eq. 7	$K_2CO_3 + HNO_3 \rightarrow KHCO_3 + KNO_3$	NOx Reactor	Rapid reaction releasing heat. Generates some end product.
End Products — Outside of the Ewan Reactor, using the Cooper Chemistry			
Eq. 8	$KNO_2 + H_2O_2 \rightarrow KNO_3 + H_2O$	Oxidizer	Captured CO_2 is liberated and stored.
Eq. 9	$\text{Heat} + 2\,KHCO_3 \rightarrow K_2CO_3 + CO_2 + H_2O$	Decarbonator	Potassium Nitrate end product. K_2CO_3 Reagent is regenerated.

Notes:

1. K_2CO_3 is a regenerative reagent with regeneration occurring in the decarbonator as the captured CO_2 is stored.
2. KOH is added to the reagent mixture as a molar equivalent to the potassium removed as a reaction product.

D) Carbon Dioxide Removal — Description of CRS Steps

Reactions inside the Aerodynamic Reactor and Aerodynamic Coalescer:

$CO_2 + KOH_{\text{(reagent)}} \longrightarrow KHCO_3$ (Carbon Capture)

$CO_2 + K_2CO_{3\,\text{(reagent)}} + H_2O \longrightarrow 2\,KHCO_3$ (Carbon Capture)

Possible Transient Reactions (to be verified):

$CO_2 + H_2O \longrightarrow H_2CO_3$

$KOH_{\text{(reagent)}} + H_2CO_3 \longrightarrow KHCO_3 + H_2O$ (Carbon Capture)

Conventional Reactions after leaving the Aerodynamic Coalescer:

(Decarbonation[3])

$$\text{Heat} + 2\,KHCO_3 \longrightarrow K_2CO_3\ _{\text{(regenerated)}} + CO_2\ _{\text{(liberated gas)}} + H_2O$$

Table 6: Reagent Parameters and Measurable Parameters (to be tested and refined) by Process Engineer:

Module	Reagent	Molarities Ratio to Target-Pollutant	pH	Testing + Refinement	Remarks
Metals	H_2O_2	≈ 1.3 : 1.0 for Mercury / Metals	6.0 - 7.0		Ratio may be "overkill"
	HCl ?		≈ 6.0		Is optional
SO_x	KOH	≈ 1.3 : 1.0 for SO_2	8.0+		Ratio may be "overkill"
	+ Re-circulation of K_2CO_3	≈ 2.0 : 1.0 for CO_2	≈ 11.0		Ramping up "overkill" from Recirculation Tank
NO_x	KOH	≈ 1.2 : 1.0 for NO_2	9.5+		NO_x prefers higher pHs
	H_2O_2	≈ 1.3 : 1.0 for NO	≈ 7.0		NO is very small amount
	+ Re-circulation of K_2CO_3	≈ 2.0 : 1.0 for CO_2	≈ 11.0		Ramping up (see above)
CO_2	KOH	≈ 1.2 : 1.0 for CO_2	9.5+		Ratio may be "overkill"
	+ Re-circulation of K_2CO_3	≈ 2.0 : 1.0 for CO_2	≈ 11.0		Ramping up (see above)

Table 7: Gas Composition (to be verified and refined by Process Engineer) for:

No.	Coal Type	SO_2 (ppm)	NO_2 (ppm)	CO_2 (% by Vol.)	Sulfur (% by Wt.)
1	Illinois Basin Coal	1,800 – 2,200	500 – 700	13 – 15	3.0 – 4.0
2	PRB Coal	200 – 350	150 – 250	12 – 14	0.4 – 0.6
3	North Dakota Lignite	400 – 600	100 – 200	11 – 15	0.7 – 1.1
4	Texas Lignite	500 – 1,200	125 – 250	11 – 15	0.8 – 2.5
5	Appalachian /Eastern Bituminous	500 – 1,500	400 – 600	13 – 16	0.5 – 2.5
6	Anthracite Coal	150 – 250	500 – 700	13 – 18	0.1 – 0.4

EXPLANATION: CEFCO'S MASS TRANSFER MECHANISM — DIFFERENCE FROM CONVENTIONAL SCIENCE:

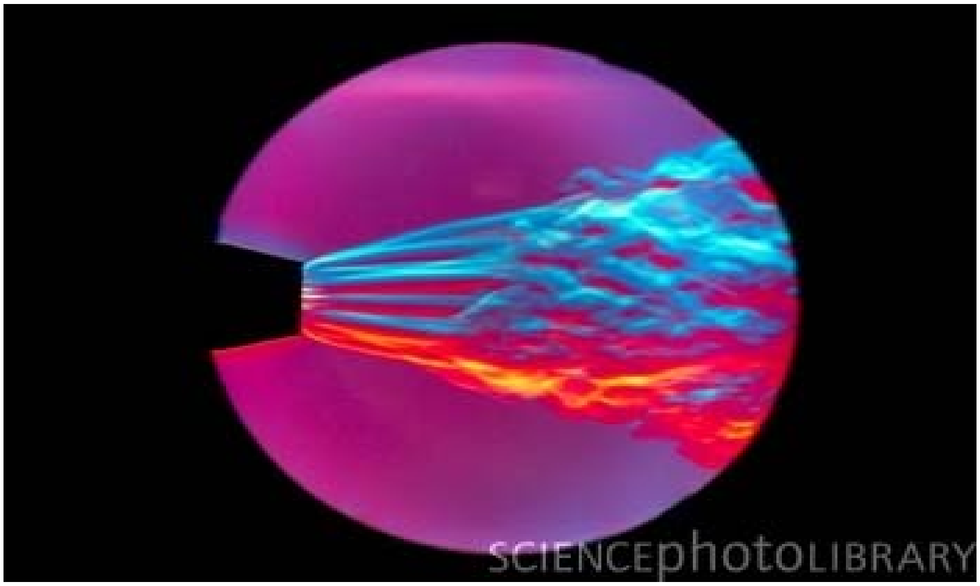
The Ewan (now CEFCO) aerodynamic process overcomes the known mass transfer barrier or resistance in conventional chemistry and thermodynamics. It has removed the consideration of fluid mechanics using Reynolds Number to a specialty within aerospace-aerodynamic science using aspects of Mach Numbers to describe extreme turbulent flow and Brownian mixing. The CEFCO proprietary process is a breakthrough innovation.

At the entrance of each Ewan reactor, steam (or a compressible fluid) is propelled through specifically designed nozzles at a designed range of supersonic speeds (a proprietary know-how) creating shock waves, which are developed at the outlet of the supersonic nozzle and extend across the conical cross-sectional area of a subsequent in-line subsonic free jet nozzle through which all flue gas passes into the reactor. All molecules of the flue gas will be collided with turbulently and repeatedly by the shock waves and no molecule can escape its effect. The flue gas molecules are accelerated by impact and momentum transfer to a high speed thereby causing multiple chain-collisions subsequently. The shock waves are very thin regions of massive energy expression within the reactor. The velocity, temperature, density and entropy are changed abruptly by the shock waves which may act like a solid body.

Supersonic Shock Waves enabling unconventional reactions underneath

Within each CEFCO reactor system designed for specific target-capture, atomizing nozzles for injecting the reagents are allied with the supersonic shock waves to direct small liquid droplets of select-reagents into the supersonic shock wave region. When these droplets contact the supersonic shock waves they are shattered into extremely small droplets (sometimes initially oddly-shaped like "ribbons", and "strings", etc. until they envelope themselves with whatever target molecule they contact and reform into spherical shapes very rapidly), and are accelerated

by impact and momentum transfer to a high speed to the in-line subsonic nozzle forming an ejector pump which is forcing the flue gas and the fine liquid droplets to pass through the subsonic nozzle. For example, within the first reactor (the MRS), when the rapidly moving extremely small droplets strike the fine particulates or metal compounds of the emissions, the particulate or metal compounds will become encapsulated by the extremely small droplets. In the event that the liquid droplets comprise the select-chemical reagent, the desired chemical reactions will occur between the chemical reagent and the encapsulated metal molecules with minimal resistance. Since the droplets are extremely small, the "ratio of their surface area to the mass" of the droplet is very large, and therefore the chemical reaction will be initiated and completed very rapidly by the process of "surface chemistry" on a near-molecular level, in contrast to the ordinary bulk conventional chemical reaction with its related Reynolds Number and thermodynamic concerns (which are usually at atmospheric pressure requiring the input of energy and often the use of catalyst with certain requirement of "dwell-time" to force adequate contact for such reaction to occur). Similar description applies to the situation within all other reactors.



Free Jet exiting Subsonic Nozzle creating unconventional reaction zone

When the flue gas exits the subsonic nozzle, a subsonic free jet is formed because the cross-sectional area of the reaction chamber is several times greater than the cross-sectional area of the subsonic nozzle, thus permitting the subsonic jet to exit and become unbounded and unconstrained and therefore "free". Within this reaction zone, the entire body of the flue gas turbulently mixes and experiences a sudden drop in pressure together with a rapid cooling effect, partly from the rapid gas expansion and partly from some extraordinary observed phenomenon. Due to the sudden drop in temperature, water vapor contained in the mixture condenses rapidly on whatever nucleating sites that are available. Such sites include any particulate, contaminate compounds, chemical reaction-product (if a chemical reagent was used in the reactor), or previously formed droplets. The rapid temperature drop enhances condensation or encapsulation into water droplets. Due to the turbulent conditions within the free jet, the droplets containing the sub-micronic particulates and aerosols rapidly grow in size

from multiple collisions, impactions and nucleations, as well as further condensation, until they reach a size that can be easily separated from the effluent gas stream. Thus the condition of rapid pressure drop, temperature drop and extraordinary observed phenomenon conditions are obtained. The decreased pressure also diminishes the "boundary layer effects" between the gas and liquid phases (with or without select-reagents), thereby enabling the more intimate contact and mixing with each other and promoting the reactions to form the desired liquid reaction products.

Summary of the Key Technical Points

A. **The mechanism for enabling the capture of the targeted emissions is caused by the steam-propelled supersonic shock waves (injected by a supersonic nozzle) which travel at a range of velocities exceeding Mach 1 (over 1,180 ft./sec.) in-line aiming directly in the same direction as the flow of the flue gas through the ductwork and reactor unit. The shock waves are the massive release in energy as a result of massive and multiple chain-collisions. Thus the flue gas is attacked and forced through the subsequently in-line subsonic nozzle. The reactive characteristics of the flue gas are altered as a result and a new reaction condition exists within this free jet zone.**

B. **Under the free jet reaction zone, there exist a rapid temperature drop and a rapid pressure drop. The pressure inside drops into "subatmospheric" (below the normal "one atmosphere"). This is the sudden collapse (within micro-seconds) of temperature and pressure, and represents an adiabatic cooling condition which is unconventional, in which chemical reactions take place that are not expected under conventional science. [CEFCO invites interested scientists to help explain the phenomenon within this "subatmospheric" reaction zone involving Free Energy of Formation (ΔF) or Gibbs Free Energy (ΔG) and the Heat of Formation (ΔH). We theorize that the Ewan process comes to achieve the desired chemical reaction from the opposite end of the spectrum or conventional measuring scale — from the "opposite direction", because we start at the shock wave-induced high temperature and high pressure and drop downward rapidly to cross path with the reaction mechanism known to conventional science. CEFCO begins with the reactions that are normally requiring very high negative (ΔH) numbers and/or (ΔF) numbers, then subsequently with the lower negative (ΔH) numbers, and so on, and then followed by reactions showing positive (ΔH) numbers nearing the end of the reaction zone. The graphic curve to be plotted showing the temperature drop is a dramatic "V-shape hockey stick", with the uptick showing when temperature begins recovery (to be explained in Paragraph E, below). The graphic curve to be plotted showing the pressure drop is a similar dramatic "hockey stick", with the uptick showing when pressure begins recovery (to be explained in Paragraph F, below). On the other hand, conventional chemistry begins at the opposite end of the scale with the costly building up of temperature and pressure (often with the assistance of expensive catalyst) to achieve the desired reactions.]**

C. **The mechanism for capturing the targeted compounds is governed partially by the surface area between emissions and the capture mechanism. By using steam, instead of water, the contact surface area is multiplied many times. For example, a single water drop (H_2O), having a surface area of 0.031 sq. centimeters when subdivided into a steam colony of one micron droplets as in steam, will experience an increase in surface area from 0.031 to 31.0 sq. centimeters (i.e., a multiple of 1,000 times the original surface area). Furthermore, when the steam micro-droplets is shattered by the shock waves, the reformed sub-micro-droplets become even tinier, so that the ratio of the increase in surface area further increase by another thousand or more times to approach the near-molecular level. Under this new reaction condition, the intended chemical reactions may be completed in milliseconds, and**

the primary process or mechanism becomes one of molecular surface chemistry, not conventional chemistry. The conventional mass transfer limitation will be overcome. [CEFCO invites interested scientists to help explain the phenomenon].

D. **For an example, the sudden decrease of temperature causes condensation of the steam or water vapor onto nucleation sites provided in the first reactor by the finest particulates and the targeted-reaction products. Due to the turbulence and multiple mixing within the subsonic free jet, the droplets encapsulating the particulates and the reaction products grow by extremely rapid and repetitive impaction, interception, diffusion, reaction, nucleation and condensation. Subsequent continuing impaction, interception, diffusion, reaction and nucleation are due, in part, to Brownian movement of the very small particles and ions. This process repeats itself in random order very rapidly and causes the "growth" of ever larger droplets and the encapsulation-re-encapsulation of ever more nucleating sites. The droplets form into streamlets, then merging into a liquid stream until it flows outside of and beyond the reaction zone. This liquid-phase is separated by the aero-coalescer from the gas-phase of the flue gas without any commingling between the two. The higher temperature travels with the gas at the top half, and the reaction-product stays inside the cooler liquid flowing downward, which exits the aero-coalescer in a stream.**

This is a proven result, and the very early version of the Ewan process was tested and reported by the EPA in "EPA-650/2-74-028" (published April 1974) stating:
" . . . the collection efficiency for the mass mean diameter for 1.0 micron was 99.90% at instant and 99.80% over a two days of testing. Measured fractional efficiency was about 90.0% for 0.01 micron. . . " This excerpt is found in the "CONCLUSIONS" of the above-cited EPA Report:

Item 1. EPA System Evaluation of the Steam Hydro by Joseph D, McCain and Wallace B. Smith for EPA Project Officer: Dale L. Harmon (April 1974).

With numerous successful test results over the past 30 years, the EPA has adopted the Ewan "free jet collision" scrubber system as one of the components of the Standards for the Maximum Achievable Control Technology ("MACT"). The Department of Energy's Nuclear Regulatory Commission has installed it and it has been in continuous use for the past 25 years for the capture and removal of Low Radiation Waste, Toxic and Acidic Waste Incineration Air Emissions at the US Nuclear Facilities, such as Savannah River, Oak Ridge, Los Alamos, Paducah and Hanford.

Bringing it up-to-date: In joining with CEFCO's co-inventors, Tom Ewan and the CEFCO team has now vastly improved upon the early Ewan invention in total efficacy and range of pollutants capture and products recovery.

E. **The aerodynamic reactor chamber and the aerodynamic coalescer are designed to provide temperature recovery in its own fashion. The unique advantage of CEFCO's swift moving gas flow reaction technology, wherein each reactor system having its own free jet reaction zone measuring in different inches of travel distance for the flue gas and different time spans**

from the beginning point of the free jet allows several molecular-surface chemical reactions to take place moving from one cross-sectioned portion of the zone to another cross-sectioned portion of the zone without much interference and commingled side-reactions to confuse the desired result (which frequently occur in conventional chemistry employing bulk gas-phase contact, which would seem in context very slow or lacking in mass displacement from Point A to Point B, so that many near-contemporaneous side-reactions take place in commingled spaces and time spans). However, inside the CEFCO equipment, each cross-sectioned portion of the zone is like a different floor of a three-floored factory, each with its own room (spatial volume) for the unconventional chemical reactions to take place within. Many of the target-pollutant capture by Hydroxide ions take place very early in the beginning microseconds or milliseconds (at the top-floor of the factory), which are generally absorbing a great amount of inputted heat (endothermic) during the rapid plunge in the observed and measured temperature and pressure inside the strong "subatmospheric" zone. Then other transitional reactions occur (usually involving the swapping of the captured pollutant's and carbonate's negative ions between H^+ and K^+) in the middle-floor a few milliseconds later inside the weaker "subatmospheric" condition. In a condition as described in Paragraph B (above), the CO_2 is now captured into an ionic compound, trapped in an alkaline solution at a temperature significantly below its liberation temperature of approximately 178°F, so it cannot rejoin the gas phase. This is the CEFCO breakthrough method for capturing CO_2 that is not done in conventional chemistry. Then a few more milliseconds later, at the tail-end of the free jet (where pressure begins to recover), the exothermic reactions (giving off heat) occur in the bottom-floor of the factory inside the very weak "subatmospheric" condition, usually involving the conversion of the Carbonate reagent into a Bicarbonate Intermediate-Product or involving the forming of the Fertilizer Intermediate-Product or End-Product and the forming of Water (all designed to be exiting the coalescer). Thus, the temperature is significantly recovered by the exothermic reactions at the end of the reactor and in the transitional ductwork leading to the aerodynamic coalescer, which is also designed with increasing conical cross-section. The conical expansion of spatial volume under plug-flow condition (to be explained in Paragraph F, below) allows for the recovery of significant pressure and assists the preservation of the temperature recovery.

F. The aerodynamic coalescer provides pressure recovery. The design of each aerodynamic coalescer is proprietary. This is a unique CEFCO advantage for both minimizing "parasitic load" in the system, as well as providing a gas/liquid separation device that does not interfere with or interrupt the swift flow of flue gas but contemporaneously causing the falling liquid carrying the captured pollutant to flow out of each module of the system via the coalescer. The gas phase (of the flue gas) and the liquid phase (of the captured-laden liquid) are aerodynamically separated in a chamber of increasing conical cross-section which removes the liquid flowing towards the bottom from the rest of the onward-moving gaseous stream. The gas flows along the top half of the increasing conical cross-section, expands due to increasing room and recovers significant pressure, and continues to flow upward and onward to subsequent reactors/aero-coalescers, and so on. The gradient of expansion is a calculated aerodynamic design to enable a controlled recovery, and not a "free" expansion which has the opposite effect. Thus the parasitic load is minimized.

More details: **As explained (above), there exists a sudden and major drop in pressure inside the reaction zone created by the subsonic free jet that will be even lower than the transport pressure of the flue gas flowing through the entire system. Since there are more than one such reaction zones due to more than one identified emissions reactors, these drops nominally represent the "parasitic load" to the host facility (the electric power generator). In the CEFCO proprietary technology, the diameter of the free jet nozzles will be designed to provide a specific net delta pressure drop (net ΔP) at each reactor. This (net ΔP) will be limited by the parasitic load the host will accept, balanced by the HP required to overcome the (net ΔP) and convey the flue gas to the stack. Generally, the (net ΔP) across each of the reactors will be somewhere in the range of : R_{X1} = 2-4 in. w.c., R_{X2} = 2-3 in. w.c., R_{X3} = 1.5-2 in. w.c., R_{X4} = 1-1.75 in. w.c. In each specific design, the nozzle diameters will be designed such that the net pressure drops (net ΔPs) will decrease in magnitude at each subsequent nozzle. For expected range of (net ΔPs) to be measured: see Table 2, (p.3, above).**

G. **Since each group of emissions targets are removed in sequence, the flue gas processed through the CEFCO system will emerge as a near-zero emission stack gas. Thus, the objectives of Carbon Capture and Air Quality Control System ("AQCS") will be met in compliance with current and future governmental requirements. CEFCO could become recognized as the Maximum Achievable Control Technology Standards ("MACT") for air emissions in the Power Industry and in all Fossil-Fuel and Petroleum-related Industries, surpassing all lower expectations and standards of the Best Available Control Technology ("BACT").**