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Energy – Coal – Capture Carbon Dioxide, Uses, and/or Sequestration

Reducing global green house gases in meaningful quantities

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Major carbon dioxide (CO_2) emitters

- The world's major green house gas emitters are:
  - Coal fired boilers in power generation
  - Road transport industry
  - Steel production
  - Sea transport
  - Air transport
- Amongst these green house gas emitters, capturing carbon dioxide from the coal fired boilers is the most economical. Sulphur dioxide removal is integral part of carbon dioxide capture. In a properly designed plant 85 to 90% of carbon dioxide and 98 % of sulphur dioxide can be captured and removed.

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India - Solar, Wind, Gas and Coal - Comparison of power developed – 2020-21

	Solar	Wind	Coal	Gas
Installed generation capacity in MW-hr	36910.53	38433.55	209294	24924
Total annual power supplied in 20-21 in MW-hr	60,402,000	60,150,000	981,239,000	51,027,000
Utilization factor (%) = Total power gen ÷ (Installed power x 8760)	18.68	17.87	53.52	23.37
Market share %	4.40 %	4.38%	71.47%	3.72%
Comments	Peaks March to June. About 50% in winter months	Peaks in monsoon when demand is low	New plants for 50,000 MW-hr being planned	GoI wants to increase gas share from 6 to 15%

Notes: 1. All values are approximate based on web information. 2. MW-hr = Megawatt hour, Hydro (11.7) & Nuclear (3.4).
2. Gas share of 6% is based on both power, petrochemicals (including Urea production) and domestic (cooking gas) use.

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Comparison of emissions from various CO_2 emitters

Table 1: Annual Carbon Dioxide Emission Comparison – all values are approximate				
#	Type of generation	Thermal efficiency	Power (kW-hr)	CO2 emissions in tons/yr
1	100 Megawatt gas based co-generation power plant	~ 55 -60%	100,000	~350,000
2	100 Megawatt gas turbine driven compressor - LNG Plants	~34 to 35%	100,000	~585,000
3	100 Megawatt coal fired power plant (steam generation and steam turbine driven generators)	35 to 45%	100,000	~400,000 + @3 to 10% CO2 content adsorbed with coal
Notes: Annual equipment usage: 8760 hours, Ambient temperature: 40^{o}C, R.H. 60%				

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Coal fired boilers are ideal to capture carbon dioxide (CO_2)

- The concentration of carbon dioxide (CO_2) in flue gases is dependent on the properties of coal. It can have CO_2 content of up to 18 to 20%, and ash content of 2 to 30% by weight.
- The economics of carbon dioxide separation from flue gases is affected by its amount in the fuel and the air- fuel ratio used in the particular equipment.

Table 2: Flue gas specification (by volume percentage wet)		
	Coal Fired Boiler Exhaust	Gas Turbine Exhaust
Air Fuel ratio (approx.)	~ 2 : 1	~ 45 : 1
Carbon dioxide	~ 9 to 15 %	~ 2.75 %
Water	~ 6 %	~ 9 to 10 %
Nitrogen	~ 70 %	~ 72 to 73 %
Oxygen	~ 14 to 16 %	~14.5 to 18 %

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Post combustion carbon dioxide (CO_2) capture technologies

- Amine plants to capture carbon dioxide in gas have been in operation for 80 years.
- The unique nature of the flue gases presents some challenges for recovery, namely:
  - Low concentration of CO_2 requires large gas volumes be treated,
  - Low flue gas exhaust pressure requires losses to be minimised in the CO_2 capture process,
  - Oxygen in the flue gas degrades liquid solvent,
  - The SO_2 and NO_2 in the flue gas reacts with the amine solvent to form heat stable amine salts that increase solvent losses and cause equipment corrosion.
  - The flue gas stream fly ash and soot in coal fired plants causes corrosion, erosion; solvent degradation, loss and sludge formation.

Carbon dioxide (CO_2) capture economics – power required

- Typically 30% or more fuel energy is lost through the stack in coal fired boilers with flue gas temperature ranging from ~175 to 220^{o}C. This is dependent on:
  - The dew point of the flue gas to prevent sulphur dioxide and carbon dioxide forming corrosive acids in combination with the water vapour in the flue gas.
  - Stack height required to meet local emission standards for dispersion of SOx, NOx and soot.
  - Availability of heat recovery process.
- Removal of soot, CO_2, SO_x, NO_x, and soot reduces the discharge temperature & stack height required to achieve a desired dispersion, thereby supporting greater flue gas heat recovery which is used to offset power consumed by the CO_2 capture process.

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Post combustion carbon dioxide (CO_2) capture technologies [1]

- Amine based process plants with CO_2 removal rate of 3000 tons per day from high pressure process streams have been in operation since the mid 1990s.
- Low pressure coal fired boiler with CO_2 capture rate of 2200 tons per day has been in operation since 2014.
- Chemical absorption involves contacting the exhaust gas with a solvent that removes CO_2 through an exothermic chemical reaction that can be reversed upon heating. A number of patented solvents (primarily organic amine based chemicals) are available. Various amines exhibit different properties in terms of their affinity for CO_2, the heat required for regeneration, corrosivity (function of the dissolved CO_2) and regeneration stability.

Post combustion carbon dioxide (CO_2) chemical absorption [2]

- Prior to entry to the CO_2 recovery process, the exhaust gas at 1.3 bar pressure is cooled to around 50°C and fly ash, soot and other impurities removed as far as possible.
- Exhaust gas enters the packed column absorber at the bottom and contacts the alkanolamine absorbent in counter current flow as it rises up. The CO_2 is chemically bonded to the solvent and the treated exhaust gas leaves the adsorber with CO_2 content typically less than 2%.
- Most industrial applications use an aqueous solution with MEA concentration between 15 and 30%.
- A water wash system is used in the top of the absorber to minimise absorbent carry over in the exhaust flue gas.

Post combustion carbon dioxide (CO_2) capture technologies [3]

Performance parameters for a CO_2 recovery system using conventional MEA solvents is given below:

- Monoethanolamine (MEA) require regeneration heat of ~ 4 MJ/kg of recovered CO_2,
- The economical CO_2 recovery limit is approximately 90 to 92% for an 8% CO_2 concentration in the exhaust flue gases of the coal fired boilers.
- Sterically hindered amines offer significantly better performance, lower steam and solvent flow rates, lower solvent consumption, significantly lower power consumption, reduced corrosion rates of steel though they tolerate lower SO_2.
- In sterically hindered amine the nitrogen atom in the amine molecule is shielded such that the other larger molecules are unable to react with the nitrogen atom.

Fig 1: Amine CO_2 removal system

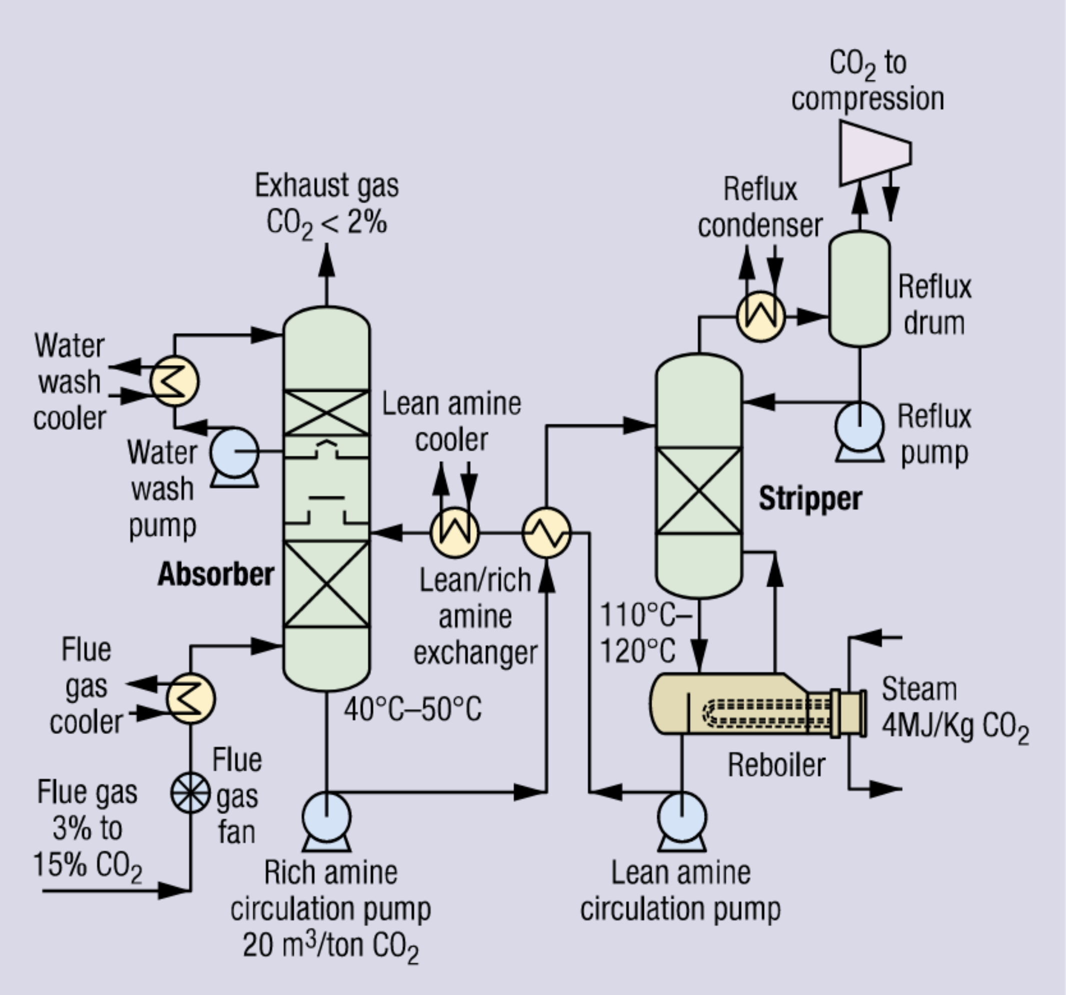
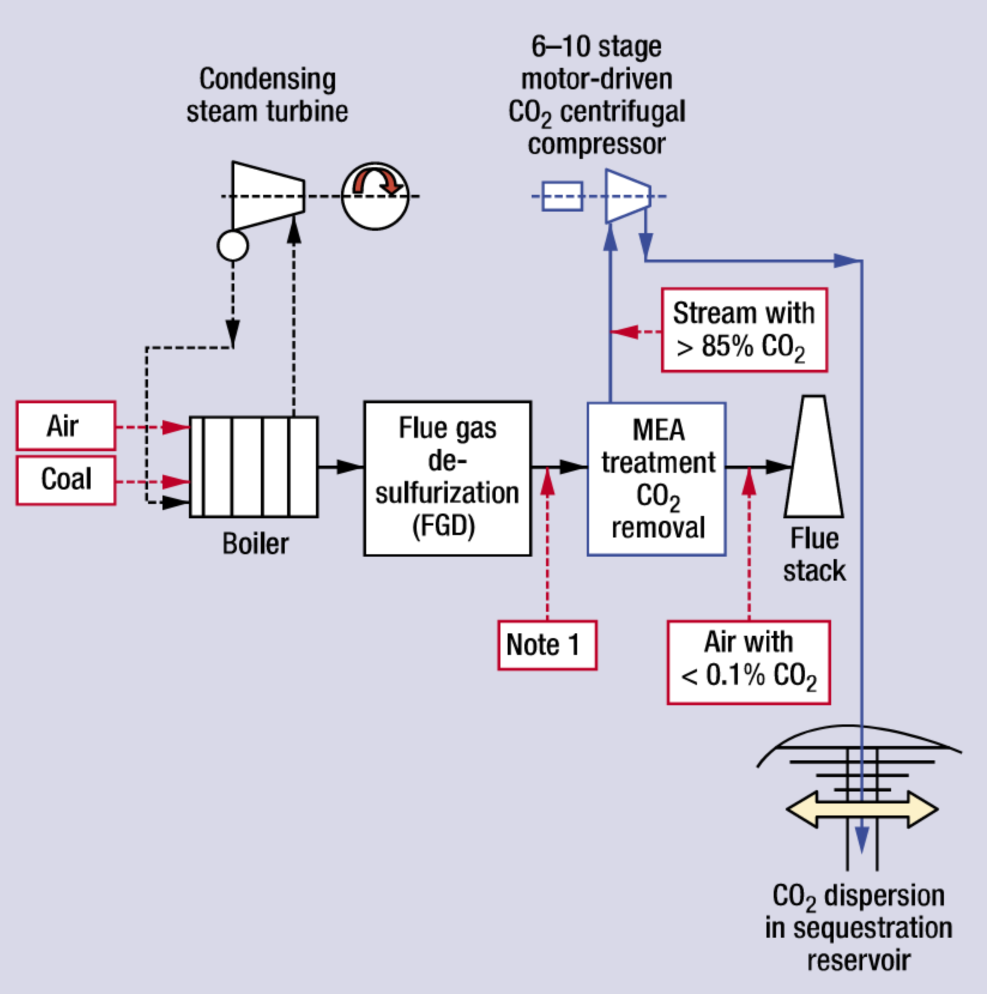


Fig 2: Coal fired Boiler CO_2 removal system



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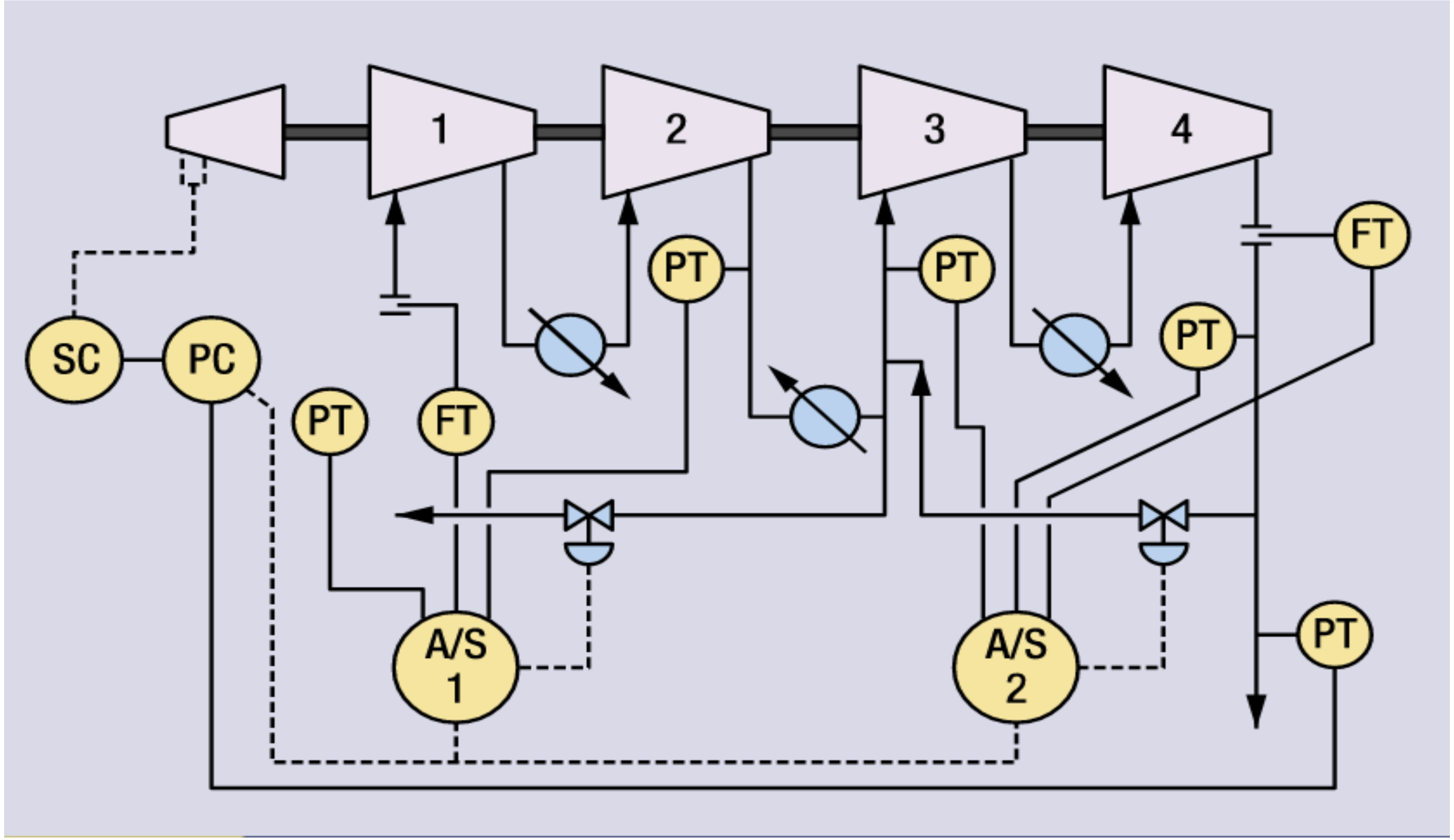
Carbon dioxide (CO_2) compression and control schematic



Thanks to Compressor Control Corp. Originally appeared in Hydrocarbon Processing, December 2006 issue, Used with permission, www.hydrocarbonprocessing.com

CO_2 compression – Integrally geared multi-stage compressor for 500,000 TPA plant

Compression stage/unit	1	2	3	4	5	6	7	8	9
Actual inlet flow, m^3/hr	30,411	16,755	9,029	4,780	2,544	1,390	763	406	198
Suction pressure, kPaa	115	208	384	714	1,321	2,323	3,984	6,700	11,111
Discharge pressure, kPaa	216	392	722	1,329	2,331	3,996	6,713	11,123	18,000
Pressure ratio	1.881	1.881	1.881	1.861	1.765	1.720	1.685	1.66	1.62
Operating speed, rpm	4,975	4,950	4,950	9,880	11,850	11,800	14,560	14,625	14,000
Discharge temperature, °C	97	97	97	96	92	89	89	87	87
Differential head, kNm/kg	42.1	42	41.7	40.5	36	32.9	29.7	25.7	19.5
Compression efficiency, %	85	85	85	85	83	83	80	78	78
Power required, kW	786	783	777	755	688	628	588	523	395
Motor power required, kW	6,610 (including losses and 10% power margin)								

Note 1. CO_2 properties; molecular weight, 44.01; gas density, 1.98 kg/m^3; liquid density, 960 kg/m^3 at minus –6°C; density at super-critical condition, 467.74 kg/m^3; critical temperature, 31.1°C; critical pressure, 73.85 bar abs; gas-to-liquid ratio, 485:1.

Note 2. Dry super-critical CO_2 is inert; however, it is very reactive in the presence of water or sodium chloride brines and, though compressible, behaves like a liquid.

Note 3. Gas flow, 57,077 kg/hr; suction temperature for each stage pre-intercooled, 40°C; gas properties in mole percentage, CO_2 = 89.95; carbon monoxide = 3; O_2 = 2; nitrogen = 3; H_2O water = 2; SO_2 = 0.05; mol weight of gas = 42.3; Cp at 15°C = 36 kJ/kmol K; Cp at 100°C = 38.81 kJ/kmol K.

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Carbon dioxide (CO_2) – Options and potential uses

Carbon dioxide captured can be put to multiple uses:

- The captured carbon dioxide can be pressurised and sequestered. There is global trade and the carbon credit certificates typically trade @ US$20 per ton.
- Captured carbon dioxide can be injected in declining oil wells to enhance oil production.
- Though relatively new carbon dioxide can be converted to methanol and mixed with gasoline / petrol. Many countries are already mixing up to 10 % methanol / ethanol in their petrol.
- Carbon dioxide and Ammonia can be combined to produce Urea at industrial scale.

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