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FACULTY OF ENGINEERING

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Pressurized Chemical Looping Reforming (PCLR) Syngas Production

Introduction

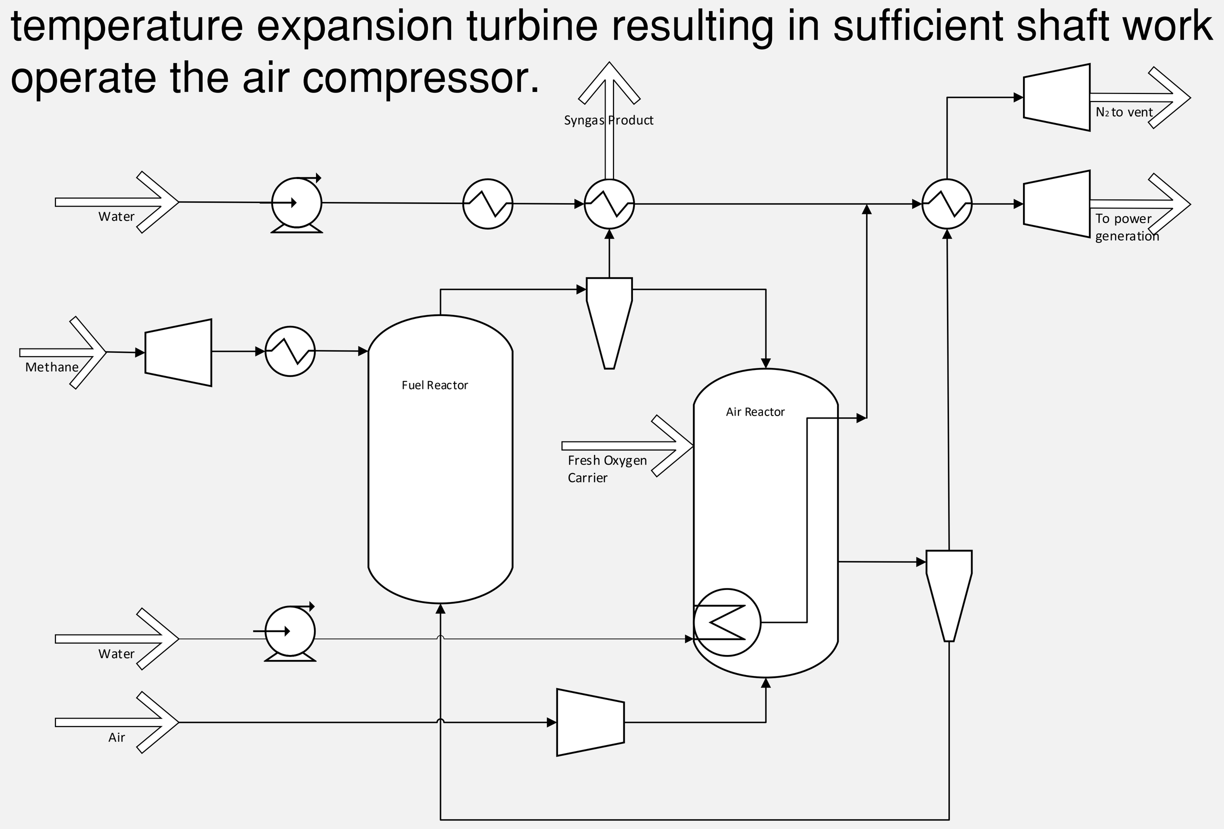
Initial Operating Conditions		
Parameter	Value	Unit
Fuel Reactor Temperature	800	°C
Air Reactor Temperature	1050	°C
Operating Pressure	2240	kPa
Fuel Pre-Heat Temperature	600	°C
Compressed Air Inlet Temperature	345	°C
Make-up Oxygen Carrier Inlet Temperature	25	°C

Project Objective:
The purpose of this report is to design and simulate an industrial scale pressurized chemical looping reforming (PCLR) process to produce syngas suitable for downstream gas-to-liquid processes

- Elevated pressures facilitate high pressure steam generation for production of electricity.
- High pressures are required to achieve high efficiency and conversion in F-T synthesis.
- PCLRs can be configured for syngas, heat, power, or steam generation processes and carbon capture
- Syngas is produced from a variety of feedstocks (natural gas, residual oil, petroleum coke, coal, and biomass)
- PCLRs may be a competitive alternative to syngas production over SMR and ATR process
- Chemical looping reforming has been implemented into many industries; however, it is not yet commercialized for industrial processing of syngas.

Design Process

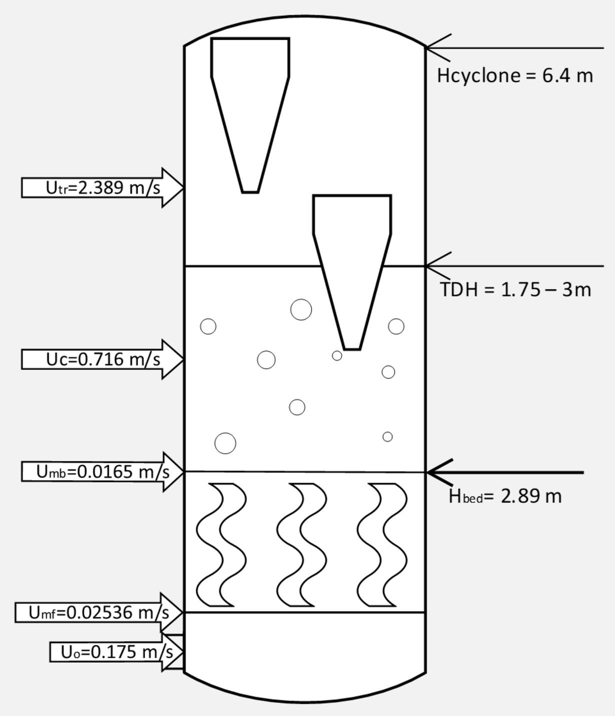
- Difficult to simulate Gas-Solid reactions in ASPEN HYSYS therefore, hand calculations, general correlations and heuristics were used for the design of major components.
- Fluidization velocities were calculated to determine the reactors’ fluidization regime and required velocity through the reactors.
- Overall reactor height determined from calculated bed height, Transport disengaging height (TDH), and cyclone regions.
- General design of cyclone and distributor plate using academic correlations.
- Elevated temperatures in both reactors facilitate steam production in both the in-bed and convective heat exchangers. Heat generated is used to pre-heat reactants entering the fuel reactor.
- Elevated pressures enable power generation via a high temperature expansion turbine resulting in sufficient shaft work to operate the air compressor.



Details of Design

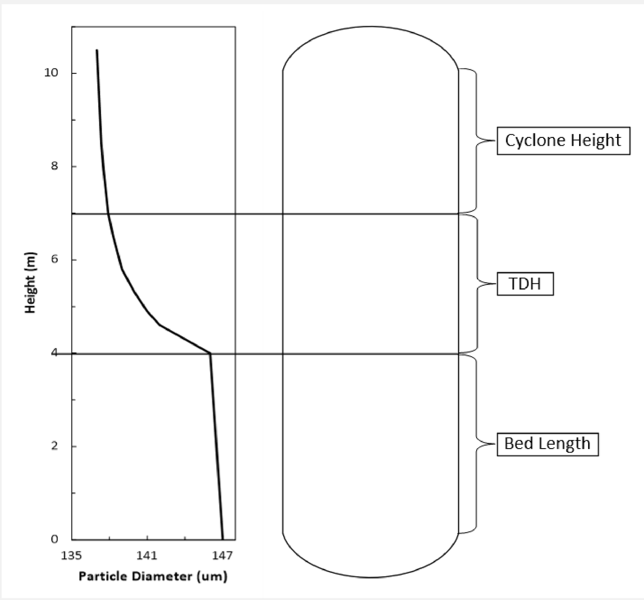
- Both reactors utilize fluidized beds
- 150 kPa Pressure drop in system

Fuel Reactor



Reactor Design Parameters			
Parameter	Value		Unit
	Air Reactor	Fuel Reactor	
Minimum Fluidization Velocity (U_{mf})	0.019	0.025	m/s
Minimum Bubbling Velocity (U_{mb})	0.146	0.165	m/s
Superficial Velocity (U)	0.155	0.175	m/s
Reactor Diameter	3.1	3.1	m
Bed Length	4	3	m
TDH Length	3	3	m
Cyclone Height	4	6	m
Reactor Length	11	12	m
Reactor Volume	83	91	m^3

Air Reactor

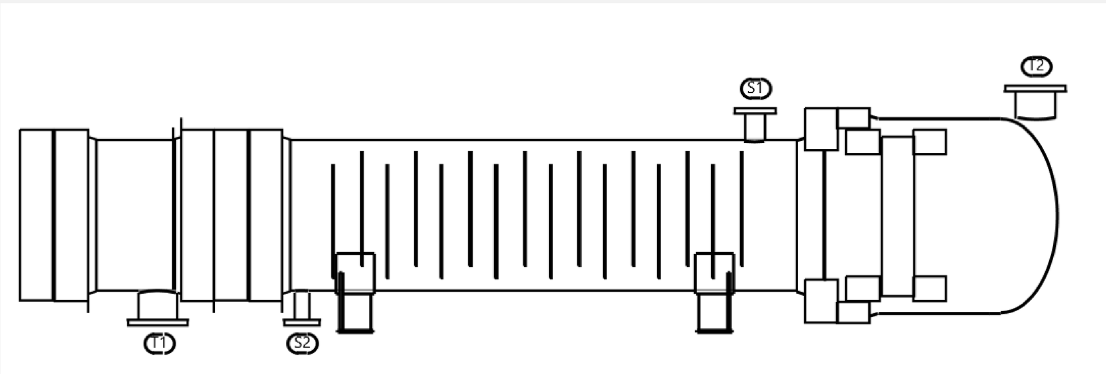


Reactor Cyclones & Distribution Plates

Cyclone Dimensions Calculator							
		High Efficiency		Conventional		High Throughput	
Model Number		(1)	(2)	(3)	(4)	(5)	(6)
Body Diameter	Dcyc/D/cyc	1	1	1	1	1	1
Height of Inlet	Hcyc/Dcyc	0.5	0.44	0.5	0.5	0.75	0.8
Width of Inlet	Wcyc/Dcyc	0.2	0.21	0.25	0.25	0.375	0.35
Diameter of Gas Outlet	Decyc/Dcyc	0.5	0.4	0.5	0.5	0.75	0.75
Length of Vortex Finder	Scyc/Dcyc	0.5	0.5	0.625	0.6	0.6	0.875
Length of Body	Lbcyc/Dcyc	1.5	0.4	2	1.75	1.5	1.7
Length of Cone	Lccyc/Dcyc	2.5	2.5	2	2	2.5	2
Diameter of Dust Outlet	Ddcyc/Dcyc	0.375	0.375	0.25	0.4	0.375	0.4

- Fuel reactor used a bubble cap plate distributor, with hole diameters of 4 mm, and 30,000 holes across the 3.1 m plate.
- Air reactor used a perforated plate distributor, with hole diameters of 0.1 mm, and 43,810,294 holes across the 3.1 m plate.

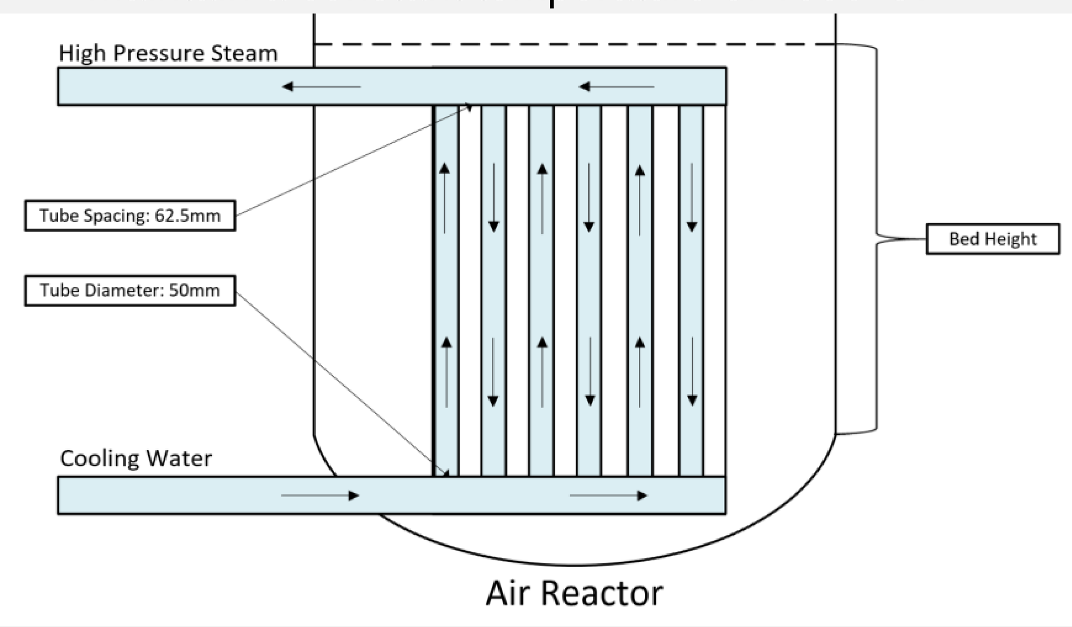
S&T Heat Exchanger for Syngas Cooling



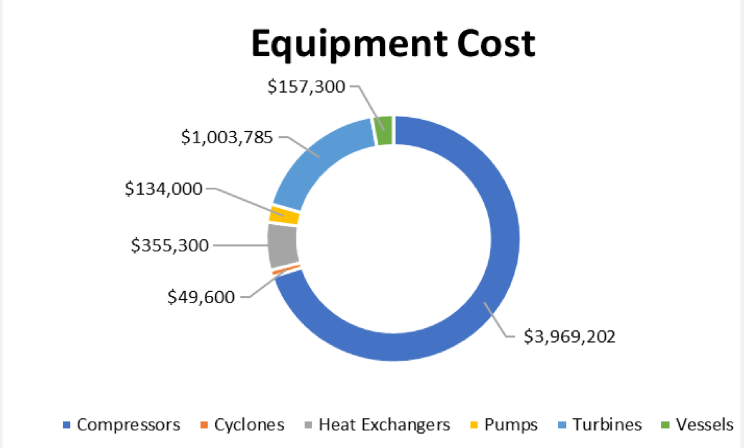
Heat Exchanger Design Parameters		
Parameters	Values	Units
Tube O.D.	0.02	m
Shell O.D.	0.68	m
Length	3	m
Total Heat Transfer Area	60.43	m^2
No. of Baffles	16	-
No. of Tubes	384	-
Syngas In	750 | 800	kg/hr | °C
Syngas Out	750 | 350	kg/hr | °C
Pre-heated Water In	7500 | 200	kg/hr | °C
Steam Out	7500 | 255	kg/hr | °C

Internal Cooling for Air Reactor

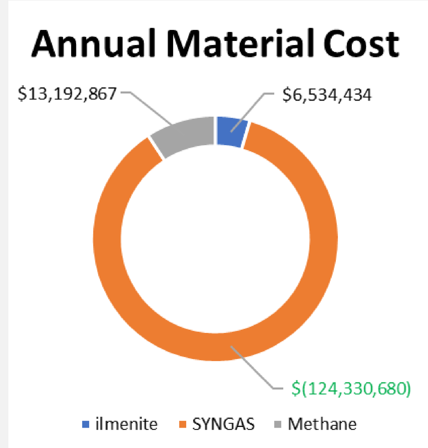
- Section cut for the bed portion of the air reactor, showcasing the air cooling heat exchanger.
- High pressure cooling water enters the bed portion of the air reactor to remove energy released from the exothermic reactions to maintain a constant temperature of 1050°C.



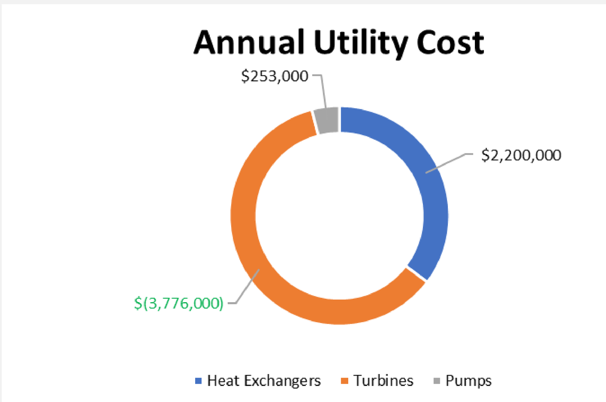
Economics



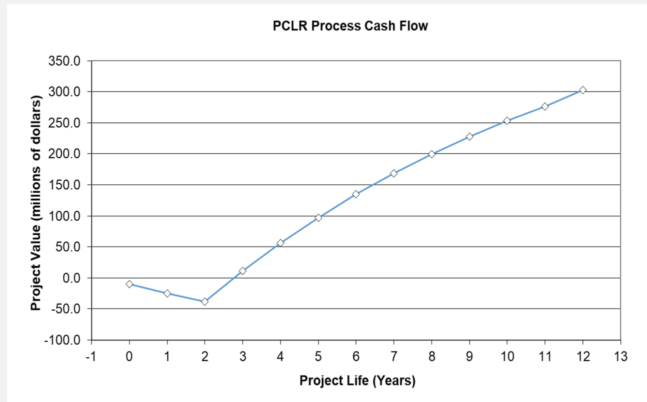
Total = $5,669,187



Total = $(104,603,379)



Total = $(13,230,000)



*Bracketed values are profits

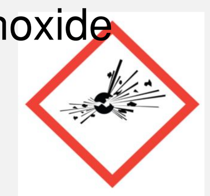
Safety Considerations

Pressurized Gas

Oxidizing Gases

Carbon Monoxide

Flammable



Explosion Hazard

Conclusion & Future Works

- Power generation from the flue gas vent and steam turbine generate sufficient energy for compressor operation.
- Future works include:
- Further experimental studies of reaction kinetics for the oxidation and reduction reactions of ilmenite with air and methane, respectively.
- Heat integrated water treatment for improved efficiency of steam production.
- Optimization of heat exchanger equipment, considering varying conditions and configurations.

References

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