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Improve Equipment Efficiency in Operating Plants

Presented by

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&

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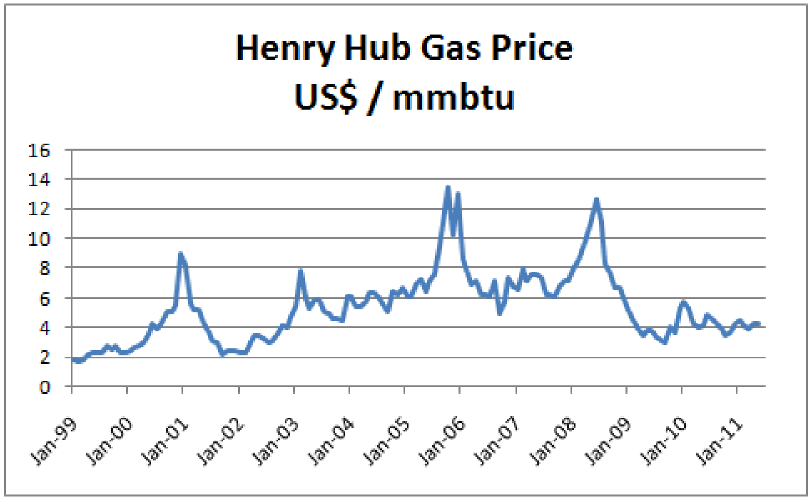
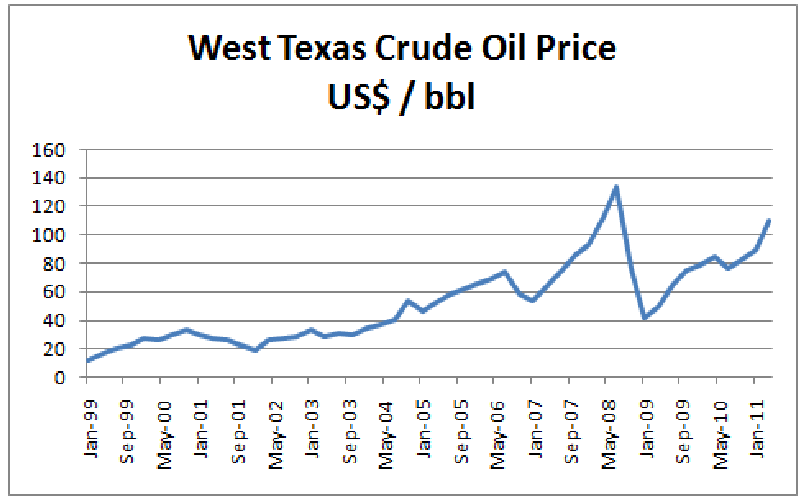
Energy Cost Pressures





Henry Hub Gas Price (1999-2011)
- Increase 7.5 times (high to Low)
- Increase 2.3 times (start to finish)

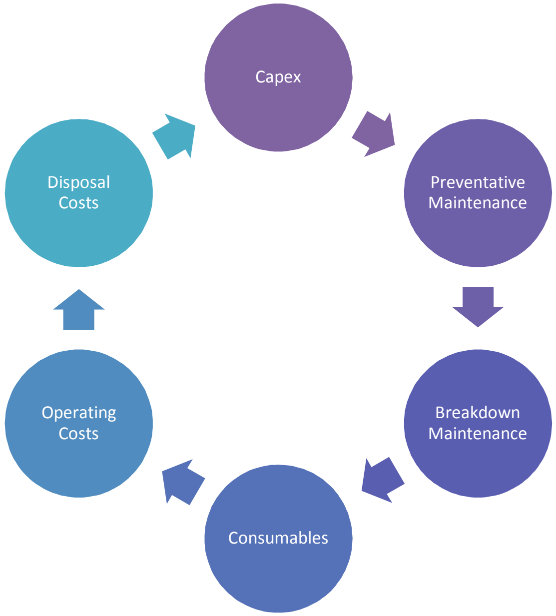
West Texas Crude Oil Price (1999-2011)
- Increase 11.2 times (high to low)
- Increase 8.2 times (start to finish)

Table 1: Energy Price for Life Cycle Cost Analysis

#	Description	Unit	Notes
1	Gas price	~US$ 3 per MMBTU	Year 2000
2	Oil Price	~US$20 per barrel	Year 2000 average
3	Energy cost	~US$0.05 per kW-hr	Used for LCCA in 2000
4	Gas price	~US$10 per MMBTU	2011, at user door
5	Oil Price	~US$90 per barrel	Year 2000 average
6	Energy cost	~US$0.1 to 0.15 per kW-hr	Including conversion

Life Cycle Costs Analysis (LCCA)

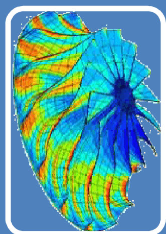
- Gas turbine driven generator set lifecycle cost breakdown (reference 1)
  - CAPEX -> 7 to 10%
  - Maintenance -> 15 to 20%
  - Energy -> 70 to 80%



- NPV = A × B × 8000 (annual saving) × 8.5 for following economic assumptions:
  - NPV (Net Present Value)
  - Energy saved per kW-hr (A)
  - Energy price (B)
  - Annual hours of operation (8000 hours)
  - 20 Years of remaining life
  - 10% discount rate

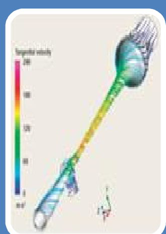
Drivers for Increased Efficiency of Process Equipment

Computer Simulation Software



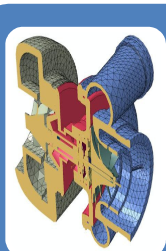
Finite Element Analysis

- Complex geometries
- Complex loading
- Structurally efficient equipment and systems



Computation Fluid Dynamics

- Models interaction between fluids and equipment
- Accurately predicts flow distribution



Multiphysics

- Real life models of coupled systems
- Fluid flow, heat transfer and chemical reactions, etc.

Computer Controlled Manufacturing

CNC Machining

- Complex Geometries
- Close Tolerances
- Complex impellers

Laser Welding

- Concentrated heat source
- Narrow, deep welds
- Welded plate heat exchanger

Vacuum Furnace

- Vacuum brazing
- Diffusion Bonding
- Aluminium plate fin heat exchanger

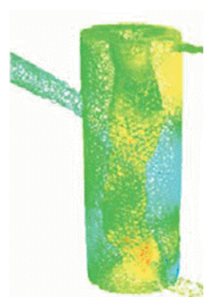
Table 2: Potential of Improvement in Equipment Efficiency

Equipment & Plant Consideration	Efficiency gain Relevant factors
Cyclonic separators	Weight & size reduction
Twister Supersonic Separator	Supersonic flow, Up to 75% pressure recovery
Compact Plate Exchangers	Weight & size reduction 1-3°C approach temperature
Compact Flanges	Higher integrity Weight reduction Proven in offshore industry
Extended Operation Between Shutdown	Up to 10% production gain Up to six years continuous operation

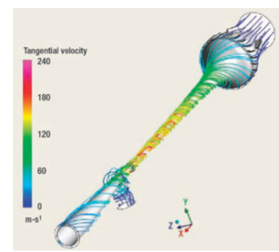
Equipment/ Plant consideration	Efficiency gain Relevant factors
Centrifugal Compressor	5 to 10%, CFD Analysis
Replacement of Wet Seals by Dry Gas Seals	~150 kW per compressor, Reduced flaring
Reciprocating compressor	Step less control, New auxiliaries
Steam & Gas Turbines	3 to 5%, New auxiliaries
Gas and Liquid expanders	5 to 10% efficiency & 1 to 2% plant throughput New auxiliaries

Application of Cyclonic Separation Elements

- Gravity Separators
- Gas Liquid Cylindrical Cyclone



- Supersonic Twister

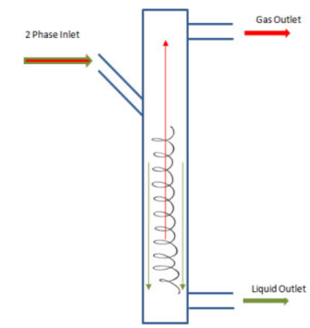


Application of Cyclones to Gravity Separators

1. Inlet Cyclone
   a) Conditions incoming fluid for subsequent separation:
      i. Converts linear momentum to cyclonic flow
      ii. Centrifugal forces promotes separation
      iii. Helps to break down foaming
2. Cyclone demisters
   a) Good gas handling capability
   b) Can reduce liquid knockout vessel size by half
   c) Maintains performance at pressures > 55 Bar
   d) In debottlenecking applications can increase vessel gas capacity by 3 times
3. Improved Separation
   a) Reduces liquid carry over minimizing:
      i. Product Loss
      ii. Downstream corrosion and fouling
      iii. Loss of expensive chemicals such as glycols, amines

Gas Liquid Cylindrical Cyclone

1. Chevron patented separator design
   a) Vertical standpipe
   b) Downward sloping tangential inlet
2. Developed via Tulsa University JIP
3. Typical performance 2 phase application
   a) 0.5 to 2 gallons / mmscf gas outlet
   b) 0 to 5% gas in liquid outlet
4. 2006 approx 700 GLCCs installed
5. Applications
   a) Production / Test Separators
   b) Separation of gas / liquid process streams
   c) Pre-separators to debottleneck existing facilities
6. Size Comparison for study of Offshore Application (70 mmscfd, 100 kbd)



GLCC in light oil steam flood application Minas, Indonesia

Compact Gas Liquid Separator	Diameter m	Length T/T m	Weight Multiple of GLCC
GLCC	1.5	6	1
Conventional Vertical Separator	2.7	10.7	8
Conventional Horizontal Separator	5.8	22.9	64

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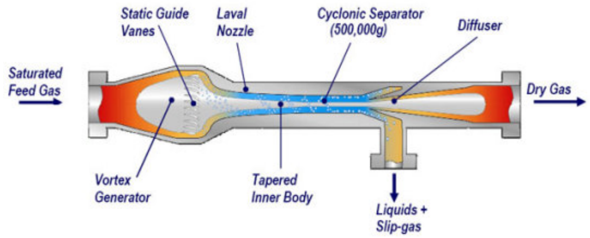
Twister Supersonic Separator

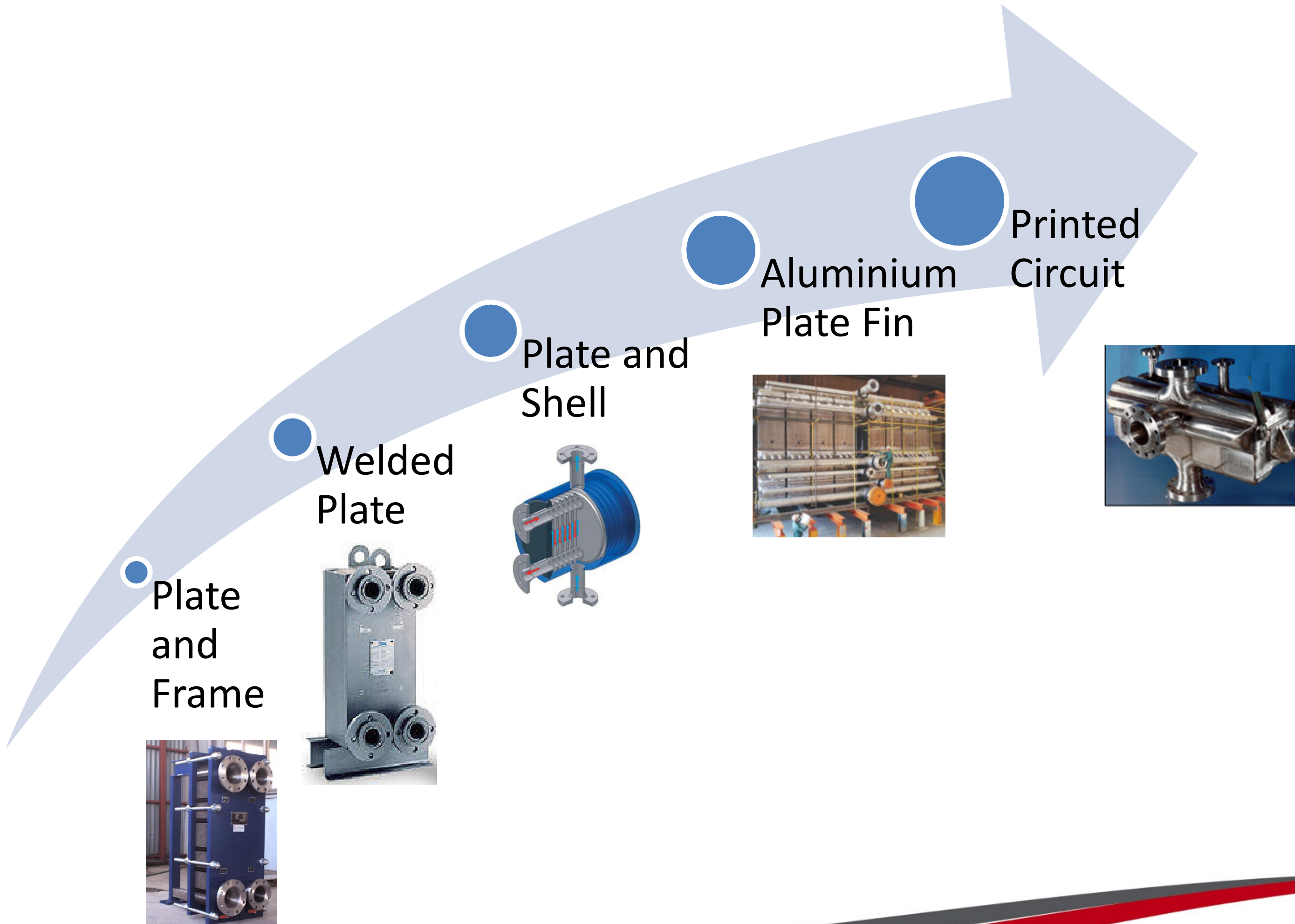
1. Proprietary static tube(s) comprising:
   a) Static inlet guide vanes
   b) Convergent annular nozzle
      i. Low Temperatures
      ii. Liquid droplet nucleation without hydrating
   c) Cyclonic Separator (liquid removal @ 500,000g force)
   d) Divergent nozzle
      i. 70 to 75% pressure recovery
2. Liquid stream separated from slip gas in compact downstream separator vessel
3. Dehydrates gas and removes NGL/LPGs in single, efficient thermodynamic device
4. Significantly smaller footprint and weight than conventional low temperature separation and glycol / silica gel dehydration systems.



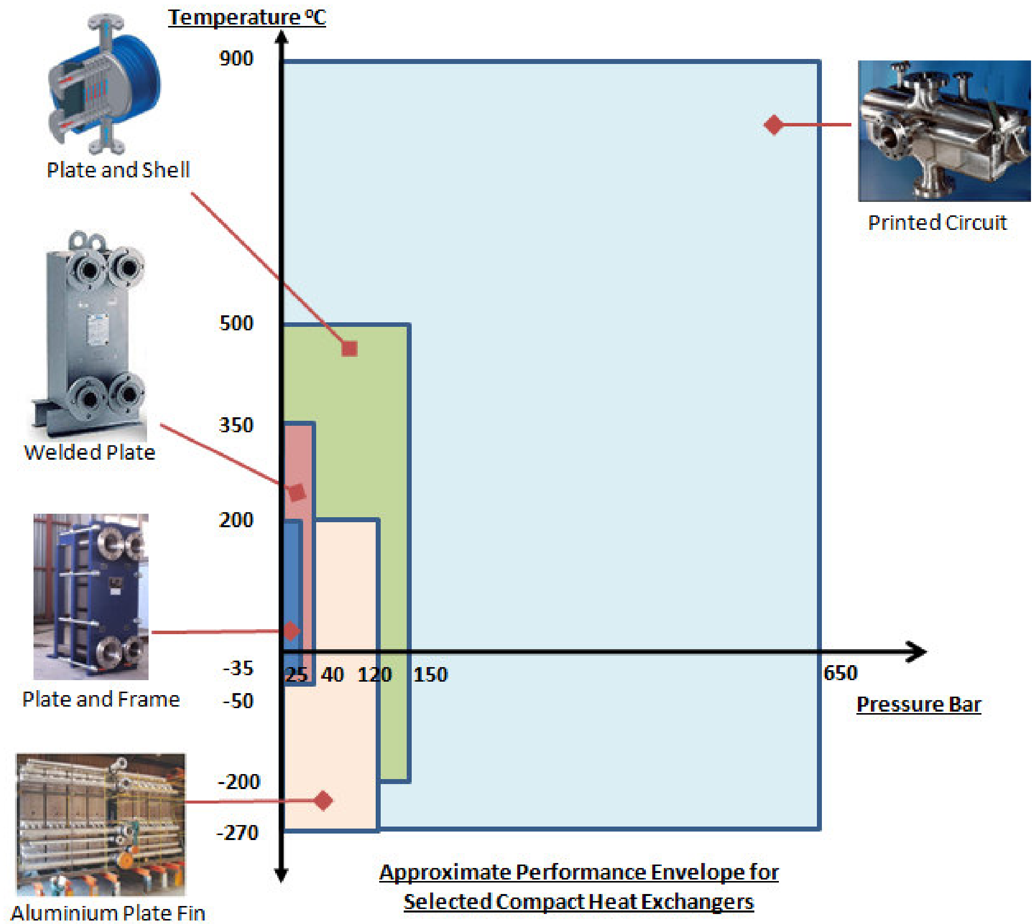
Swirl tube Schematic

6 x 105 mmscd twister tubes mounted on compact liquid degassing vessel

Development of Compact Plate Exchangers



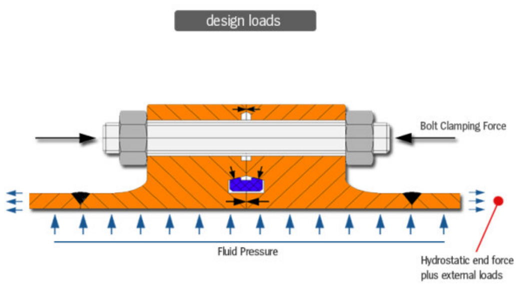
Compact Plate Exchanger Performance Envelopes

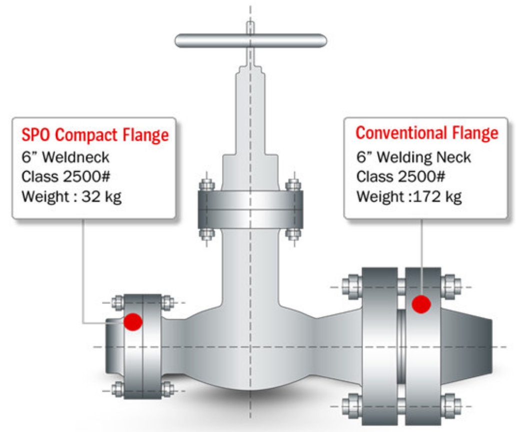


Advantages of Compact Heat Exchangers

- Corrugated Plate Design results in Turbulent Flow, and
  - Low Fouling
  - High heat transfer (3 to 5 times that of S&T HEX)
- 5 to 10 times greater heat transfer surface area per unit volume than S&T HEX
- 1/5th size of conventional S&T HEX
- Significant weight reduction; BAPHE can be 95% lighter than S&T
- Custom designed for thermal / hydraulic requirements of service
- Approach temperatures of 1 to 3^{o}C c/w 5 to 10^{o}C for S&T HEX
- Low inventory reduces plant risk exposure
- Plate and shell ideal for debottlenecking as easily fits in shell of existing S&T and Kettle Reboiler.
- High integrity of PCHEs improves process system integrity
- Lower CAPEX particularly when using exotic alloys.
- Lower OPEX due to improved heat recovery and reduction in plant heating and cooling loads.
- Narrow flow passages limits use to clean service or applications with pre-filtration.

Piping Components - Compact Flange





ASME B16.5 Piping Flange

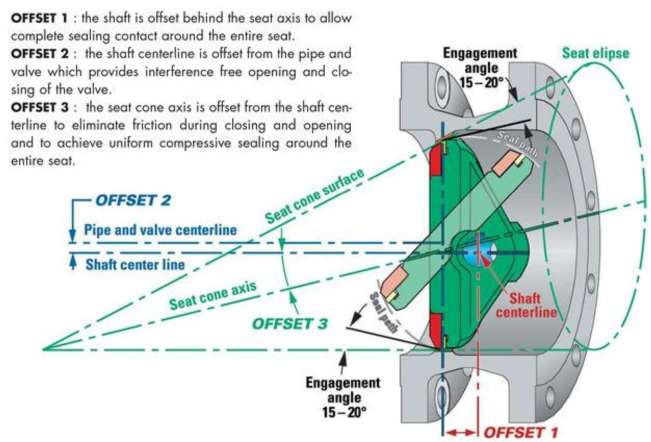
a) Sp. wound and RTJ gaskets require large seating stress
b) Bolts located outside gasket sealing face
c) Large and heavy flanges

Compact flanges

a) Low seating stress, pressure energised
b) High integrity (Press. to > 1000 Barg, Temperatures from -200 to 720^{o}C)
c) Smooth bore
d) Reusable sealing rings

Piping Components - Triple offset Butterfly Valve

- Disc / seat contact only at point of closure
- Low torque
- Bi-directional
- Metal to metal fire safe seal
- Positive closure with zero leakage to API 598 (resilient seat).
- Solid seat rings in abrasive / high temperature service to API 598 metal seat leakage criteria
- Consider for applications requiring positive isolation
- Available with flanged ends, wafer lugs and with short and long pattern gate valve face to face dimensions.
- Wide range of sizes and ratings:
  - Size 3” to 112”
  - pressure class 150# to 900#
  - -254 to 815°C
- Compact and light weight; weight comparison for 12” 600# with gear actuator:
  - Triple offset, short pattern, flanged 446kg
  - Conventional ball valve 920 kg
  - 52% weight saving



Extend Operating Time between Major Plant Turnaround

Table 4: Industry practice of uninterrupted operation between shutdown			
#	Industry / sector	Operating time between major turnaround	Driving factors
1	Refining	1 year to 4 years	1 year–boiler inspection 4 years in Australia
2	Petrochemical	1 year to 2 years	Cracked gas compressor fouling
3	LNG Plants	Usually 4 to 6 years	Gas turbine
4	Offshore Platform	As required to 3 years	Gas turbine
5	FPSO	Usually 5 years	Shipping bureau

Extend Operating Time between Major Plant Turnaround

- Regulation in some countries require boiler steam test every 11 months thereby setting operating period between turnarounds.
- Australian regulators allow longer boiler/plant operating time based on
  - operating record review,
  - boiler operating temperature records,
  - Tube metal thickness survey and verification,
  - water quality records etc.
- Current proven duration of uninterrupted operation for
  - Compressors – 8 years or more
  - Dry gas seals – 8 to 10 years
  - Gas Turbines – 4 to 8 years with short duration shutdown for boroscope inspection
  - Steam turbine – 5 years or more
- Six years of operation between major turnaround is common in LNG industry.
- Constitute program to check plant wide equipment performance and predictive health of major equipment to determine turnaround cycle and gain up to 25 days of extra production per year.

Centrifugal Compressors

- are un-spared
- have high first cost
- define plant capacity, as evident from the table below

Table 5 – Changes in plant capacity to reduce first and energy cost

#	Industry / sector	Capacity in 80's	Current 2011 capacity
1	Refining	3 to 5 MMTPA	15 MMTPA or higher
2	Ethylene	0.4 to 0.8 MMTPA	1.5 to 2.0 MMTPA
3	LNG	1.5 to 2 MMTPA	7.8 MMTPA (Qatar)
4	Offshore Compression	2 to 10,000 kW	5 to 30,000 kW

Improvements in Centrifugal Compressor Efficiency

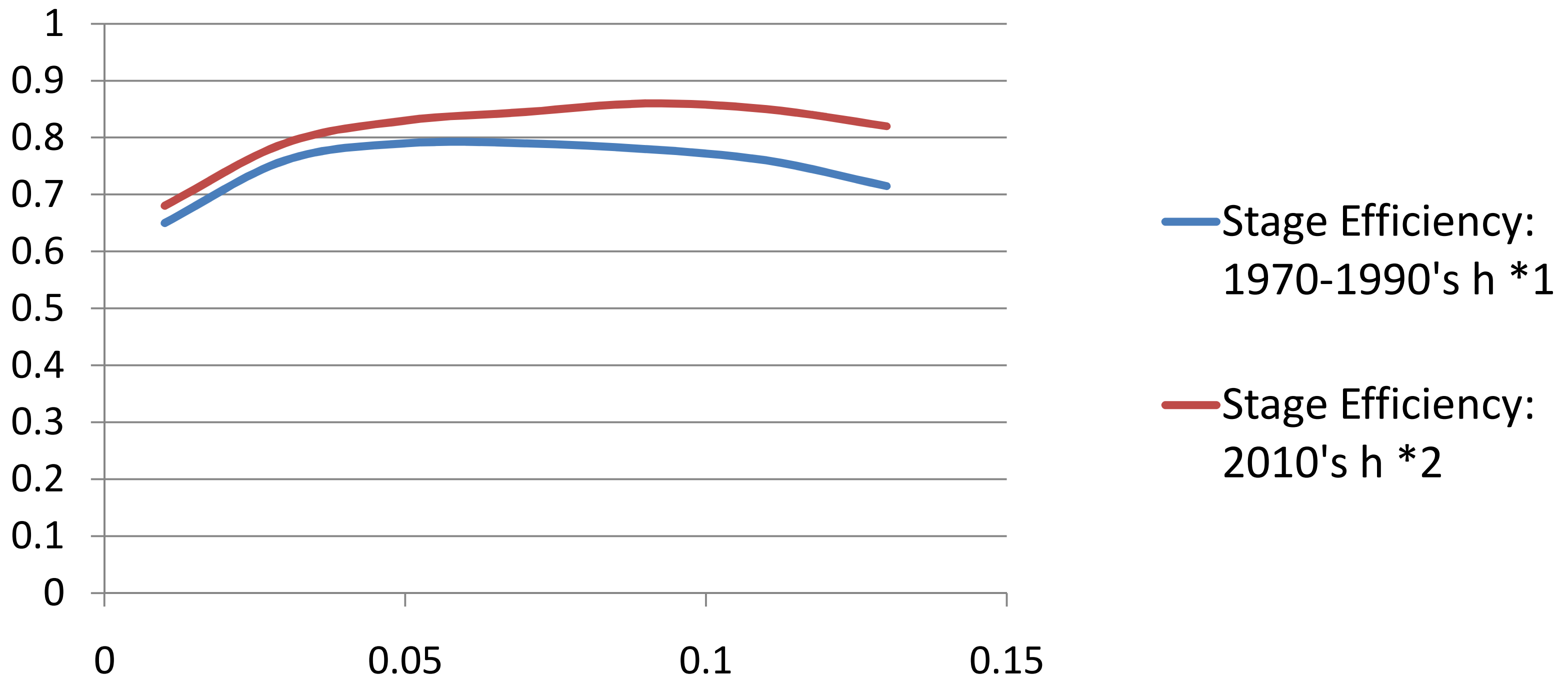
Table 6: Flow Coefficient[*3] vs. Stage Efficiency									
Year	Flow Coefficient	φ	0.01	0.03	0.05	0.07	0.09	0.11	0.13
70-90's	Stage Efficiency:	η [*1]	0.65	0.76	0.79	0.79	0.78	0.76	0.715
2010's	Stage Efficiency:	η [*2]	0.68	0.79	0.83	0.845	0.86	0.85	0.82

*1 - Source - 1980's Demag De-laval catalogue,

* 2- Efficiency range generally seen from suppliers

*3 – Flow coefficient, a dimensionless number, is ratio of actual flow divided by impeller diameter squared and tip speed, $Q/(D^2 x N x D)$. Lower flow coefficient implies increased frictional losses.

Figure 1: Centrifugal Compressors Efficiency Improvement



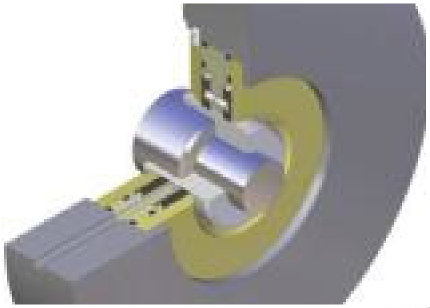
Design Improvements in Centrifugal Compressors

Many improvements in Impeller and Stator design:

- 3-d design impellers with lower frictional losses.
- Blade cutback in low flow coefficient impellers to enhance efficiency up to 1%.
- Better flow channel design available between impeller cover disk and inter-stage labyrinth to reduce turbulence loss.
- Use labyrinth materials like silicon aluminum or PEEK to reduce inter-stage losses between 2 to 5%.
- In ethylene plants, cracked-gas compression, consider Electro-less Nickel (EN) coating to reduce fouling from polymerization.
- Single piece impellers up to 1.4m diameter with lower frictional losses are available.
- In some cases, "Flange to Flange" overall efficiency up to 87% available.

Dry Gas Seals Developments

- Better understanding of seal lift off pressure and dam area to balance seal design.
- Seal lift-off at lower speeds.
- New hardened surfaces allow for extended low speed operation.
- Seal gas filters of up to 0.1micron filtration level available.
- CFD analysis to determine dynamic seat temperature.
- Seal gas dew point curves calculated to better design auxiliaries.
- Reduce nitrogen consumption by replacing separation labyrinths with floating or fixed carbon rings.



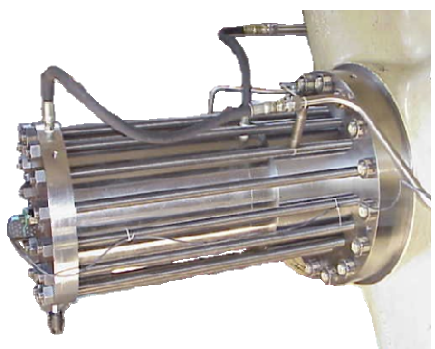
Dry Gas Seals

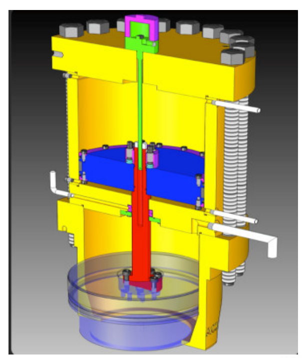
Table 7: Dry gas seals design envelope (Reference 8)		
Operating Parameter	Conventional Unit	SI Unit
Maximum dynamic sealing pressure:	6160 psig	42500 kPag
Maximum static sealing pressure:	6160 psig	42500 kPag
Minimum operating temperature:	(-) 242 ^{o}F	(-) 152^{o}C
Maximum shaft size:	13.75 inch	350 mm
Maximum operating speed:	70000+ rpm	
Normal allowable radial movement:	+/- 0.024"	+/-0.6 mm
Maximum axial movement:	+/- 0.24"	+/- 6 mm
Max. speed at balance diameter:	590 fps	180 m/s

Reciprocating Compressors

Many improvements have enhanced efficiency and reliability in following areas:

- Automated step-less control in place of step control of 0-25-50-75%.
- Use piston rod-drop measurement to monitor compressor wear rings condition.
- Gas tight piston rod wear rings available.
- Longer compressor valves life with improved PEEK materials.
- Research shows for new compressors use longer strokes instead of higher. rotational speeds to achieve higher piston velocities and reliability. (Reference 9)





Step-less control device

Steam Turbines and Steam Networks

Development in blade design, steam flow path, reduction in inter-stage and external leakage loss continue to improve its efficiency.

- Replace carbon rings with dry gas seals to reduce steam loss by up to 98%. (Reference 12)
- Consider water wash to remove built up salts.
- Consider Titanium nitride coatings on turbine blades to reduce fouling.
- Upgrade from mechanical to more reliable electronic over speed trip system.
- Consider dynamic and transient analysis of LP and HP steam to improve control ability and stability of header pressure and minimise venting losses during upset and trip conditions. (Reference 18)

Gas Turbines

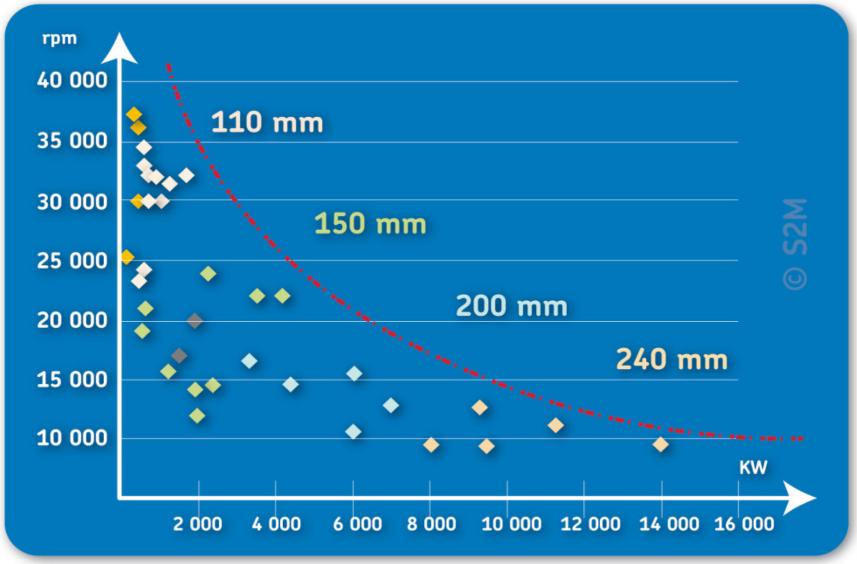
- Gas turbines ranging from 1 to 125 megawatts are used in Oil Industry.
- Poor quality traditional static inlet air filters can reduce air flow by 5%, output power by 10% and increase fuel gas consumption by 5%. Consider self cleaning filters to improve turbine efficiency by up to 10% and increase plant availability by 3 to 5 days per year.
- To improve efficiency and output
  - Replace turbine compressor aft labyrinth with brush seals (~ 0.5% each).
  - Replace with new seal materials and inter-stage brush seals in power turbine sections (2 to 3%).
- Better materials allow longer operation between inspection like
  - Hot end turbine blades made from directionally solidified steel.
  - Thermal barrier coating of hot end blades.
- Re-analyse fuel gas, consider coalescing filters to reduce fuel gas moisture to ensure longer turbine hot end life.

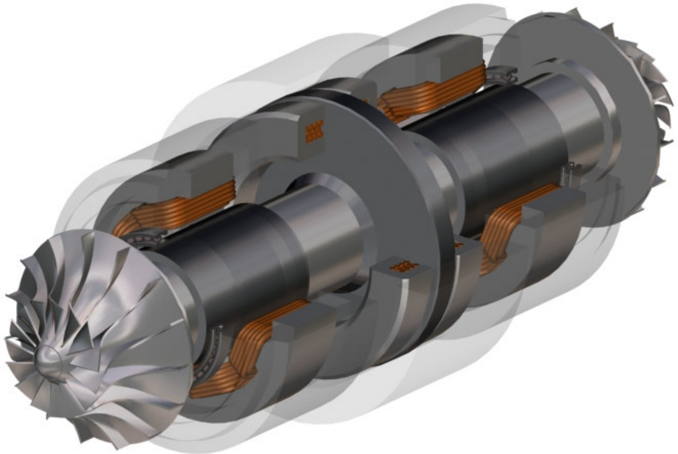
Gas and Liquid Expanders

- Consider pressure reduction of 2000 kPa (290 psi) or more across a JT (Joule Thomsen) valve as candidates for energy recovery process in expanders.
- Power ranging from 100kW to 10,000 kW.
- Expanders can drive
  - Compressors.
  - Generators.
- Potential for new applications in
  - Pipeline gas pressure let down stations.
  - LNG plants, unloading/storage terminals.
  - Offshore Platforms and FPSO's.
- Two-phase flow with recovery up to 10,000 barrels/day of LPG and Condensate.
- Pay back period's range from few months to few years.

Turbo-Expander Magnetic Bearing Experience

Earlier problems of turbo-expander bearing lubrication and separation of cold gas from bearing lube oil can be overcome by use of magnetic bearings.





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Last point

Computing power has increased transient and design analysis capability of process (gas, liquids, steam), mechanical and electrical systems.

The authors have highlighted a few of the many opportunities that exist to enhance existing plants efficiency and reduce energy consumption. Consider systematic plant equipment review to improve efficiency, availability, sustainability, profitability and reduce carbon footprint.

Thank you for your time.

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