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Oil & Gas Plant, Machinery, Design, Engineering, Operation & Maintenance, Troubleshooting Services

Global Machinery Consultants Pty Ltd., Australia

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Engineer, troubleshoot Pumps, Compressors & Turbines

- Global Machinery Consultants Pty Ltd, is registered in Australia
- **Started and based in Australia since year 2000**
- Principal Consultant & Director – Mr. Manjul N Saxena
- 32 years of design, engineering and operational experience of rotating machinery in the Oil & Gas Industry
- Based in Perth, Australia – Major Hydrocarbon Industry Centre of Australia
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Oil & Gas Operator Experience – 7 years in UK

- Projects & Operation – Concept, FEED and detail engineering development experience of rotating equipment for projects ranging from $10 million (Brown Field) to US$50 billion (Green Field).
- **Experience area – LNG, Oil & Gas, FPSOs, Offshore facilities, Refinery and Petrochemical plants**
- **2012 - 2019** – Mr. Saxena as staff of BP (one of largest companies Oil & Gas companies in the world) - Upstream Engineering Centre in Sunbury, London supported the machinery issues of the six of its eight operating regions - globally. Troubleshooting, engineering and design audit of BP projects and operating facilities. Main regions supported – Azerbaijan, Georgia, Turkey, Egypt, Angola, North Sea – UK and Norway sectors, Russia, Indonesia, Iraq, Oman, and Trinidad & Tobago.

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Oil & Gas Operator Experience

- 2019 – Report to upgrade 20 Water Injection Pumps of Rumaila Oil Field, Iraq.
- 2018 – 19 – Provided oversight to testing and installation of two 10,000 kW steam turbine in Tangguh LNG plant.
- 2018 – Providing technical guidance on compressor casing repair of MP Compressor on GtP FPSO, Angola and Flash Gas compressor in Sangachal Terminal at Baku, Azerbaijan.
- 2018 – Troubleshooting and de-bottlenecking of LP, MP and HP Compression train performances for Greater Plutonio (GtP) FPSO, Angola. LP Compressor changed due to low performance (reduction in differential head developed).

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Oil & Gas Operator Experience

- 2018 – Troubleshooting and de-bottlenecking of LP, MP and HP Compression train performances for Greater Plutonio (GtP) FPSO, Angola. LP Compressor changed due to low performance.
- 2017 – Troubleshooting of compressor reliability on Foinaven (high H_2S, iron sulphides, and mercury in gas along with marginally stable rotor) FPSO and Clair (LP, MP, and HP compressor field capacity down by 27%) platform in North Sea.
- 2016 – Design assurance review of Skarv (Norway) FPSO's LP (1000 kW) and HP (2 x 10,000 kW) Compression upgrade project. Issued **risk assessment report** on 10 - stage LP compressor and recovery measures.

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Oil & Gas Operator Experience

- 2016 – CA platform, Azerbaijan, troubleshoot high gearbox bearing temperature of four gas injection compressors, each driven by 32,400 kW gas turbines (Rolls Royce, RB 211), injecting **total one billion cubic foot of gas @375 bar (g) discharge pressure**. Recommended modification to seal cartridge system.
- 2015 – Resolved split line sealing and oil seal problems of six compressors, built in 1973, installed at Kinneil (Edinburgh) oil & gas gathering facility (~250,000 barrels of oil processed daily) ensuring continued oil production from connected North–Sea platforms. Issued guidance note for future upkeep.
- 2015 – 2016 Developed and issued **company position paper** approving use of Siemens DLE engines (SGT 100 – SGT 400) in BP projects worldwide.

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Oil & Gas Operator Experience

- 2013 – 2016 Design and engineering of flash gas compressors upgrades for East and West Azeri facilities. 4 compressors – **increased volumetric flow capacity of each compressor by ~ 60% and will enhance (additional) oil recovery by ~30+ million barrels of oil over eight years from these fields.**
- 2013 – 2015 Provided detailed technical guidance and specified requirements for the **development of the new (upstream) design of magnetic bearings by S2M** for corrosive (salty MEG) seal gas environment experienced in Sangachal's MTC turbo-expanders. The expander with new upstream design bearing was successfully installed /commissioned in July 2017 and continues to operate without any further problems. Production impact of US$12 million per year.

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Oil & Gas Operator Experience

- 2013 – Design review and risk assessment of Shah Deniz 2 export compressors (MDT casing RB 71-8, 125 bar MAWP) and issued technical requirements for **design assurance program** for manufacture of MAN's RB71-8 compressors. The design assurance required casing FEA, design review of impellers, and review of the rotodynamics.
- 2012 – Re-HAZOp / LOPA (Layer of Protection Analysis) of Greater Plutonio FPSO, Angola after 5 years of operation – (low and high pressure compression, five compressors, final discharge pressure 350 bar (g)).

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GMC Oil & Gas Operator Experience – 4 years

- **2008 – 2012** – As the lead consulting engineer of INPEX (OWNER) developed the Concept, FEED and early Engineering up to the placement of orders for Ichthys LNG at Darwin, Australia. In 2008 successfully recommended changing the train capacity from 3.6 to 5.0 MMTPA thus reducing the need from 3 to 2 LNG trains. **Total project cost > $50 billion. Developed both design and operations requirement of the facility.**
- Optimised main refrigeration compressors (Propane and Split MR, each @ 85 MW train), to operate at 98% speed of GE Frame 7 EA turbine speed.
- Select design, review / approve MCHE Feed Compressors ~37 MW VSD Motor, End Flash Gas Compressors, ~100,000 m3/hr capacity, 18 MW, LNG-BOG 3 x 4.5 MW, Propane BOG 2 x 3.5 MW Gas Compression etc.)
- Presented project business case (machinery) to international consortium of banks.

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GMC Engineering Experience

- 2006 – As consulting engineer to Clough Engineering developed the concept & FEED development of Nuayyim Oil & Gas Separation Plant – 100,000 bpd for ARAMCO – 4 process compressors, VSD motor, and number of water injection pumps. Project estimated cost > $500 million.
- LP Compressor - K003 - 550 kW
- HP Compressor - K001 A/B - 4500 kW each
- Pipeline Compressor - K002 A/B - 4500 kW each
- Overhead Stablizer Compressor - K20/21/22 - 2500 kW

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GMC Engineering Experience

- 2005 - PNG LNG Project – As Consulting engineer prepared the first report for P'nyang gas field recommending development of LNG facility at Port Moresby, Papua New Guinea (PNG) for Exxon Mobil. Benefits highlighted to clients included window of opportunity, the deepest natural harbour, low spend on jetty, combining two oil & gas fields, recommended to PNG government to consider investment and changes to certain legislatures.
- This recommendation changed the economic viability of PNG as a nation – 40+ years of royalty income from Exxon Mobil to PNG government – Plant was commissioned in 2012.

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GMC Engineering Experience

- 2002 – 2003: Gaja Baru Offshore Platform, Indonesia: FEED and partial detail engineering (resolution of deviations) of 110MMSCFD Gas flow, 2 x Solar Mars 100 Turbine Driven Compressor.
- 2005 – 2007: Gas Wellhead Compression FEED (220 MMSCFD plant). Four options evaluated - 2x100, 3x50%, 4 x 33% gas turbine driven centrifugal compressors and 9 x 15% engine driven reciprocating compressors. Prepared FEED report on the selected option of 3 x 50% (110 MMSCFD each). Later in 2007 carried out bid evaluation and detail engineering of these Siemens compressors.

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GMC Engineering Experience

- 2000 – 2002 - FEED and detail engineering of Woodside LNG train IV as consulting engineer to Kellogg JV. The design concepts of this train was copied and re-applied by Woodside for its LNG train V and Pluto LNG – Engineered to Shell Specifications.
- Engineered (at the time) World's largest cryogenic turbines and were installed with dry gas seals for the first time in LNG IV – Net Present Value of the benefit of these turbines was >150 million USD at LNG price of $250 per tonne. Field test confirmed LNG Plant efficiency was improved by 5%.

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Engineering Experience

- 1998 – 1999 – As consulting engineer to Worley ABB JV, FEED (Front End Engineering Design) - Al Shaheen, Qatar – 3 Offshore platform - 7 gas turbine driven compressors, 3 gas turbine generators, 10,000 bpd C3-C4 turbo-expanders, oil pumps etc..
- Recommended changes to the topside design which optimised the power demand and reduced power consumption saving 2,000 kW-hr of power consumption per train.
- Al-Shaheen Offshore facilities has been in operation since 2005.

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Oil & Gas Operator Experience

- 1999 – 2000 – As Maintenance & Reliability Engineer to Esso (Exxon Mobil), Bass Strait, Australia.
- Developed gas turbine (Solar Saturn, Centaur40, Centaur50 to Taurus70) driven compressor maintenance procedures for @ 20 units reducing planned shutdown period by 33%.
- Reviewed compressor failures for 1995-99 and proposed solutions improved uptime by ~1% on 12 platforms.
- Conducted root-cause failure analysis of recurring failures of 3 upgraded Solar T1600's and successfully implemented corrective measures. Also identified source of recurrent problems (high ISO VG 32 lube oil temperature in summer, > 70^{o}C) on other turbines and suggested corrective solutions that were implemented in the field by others.
- Successfully resolved compressor problems to substantially enhance gas lift on Cobia (CBC 2430, Solar Centaur) platform.

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Experience record through technical publications

We believe sharing our expertise will help to improve efficiency and reduce carbon dioxide and methane emissions.

Our technical papers, "Optimise gas turbine- driven centrifugal compressors" (Nov 2000) and "Upgrade process compressors to enhance production" (Jul 2017) in the technical journal "Hydrocarbon Processing" has had significant worldwide impact on the offshore /onshore gas compression engineering practices.

GMC can assess and identify opportunities to improve your facility throughput by increasing existing volumetric compression capacity (as high as 60%) or by increasing the discharge pressure or lowering the suction pressure to maximize production of ageing facility. We can also help reduce your power consumption.

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Supplier Experience Track Record

- Compressor suppliers interface with – GE, MAN Turbo, Siemens, MHI, Elliott - Ebara, Dresser Rand, IHI, Solar, and BHEL
- Centrifugal Compressors built to API 617
- Lube oil and dry gas seal support system built to API 614
- Power consumption from 1000kW to 100,000 kW compressors
- Compressor flow rate up to 250,000 actual m^3/hr
- Discharge Pressure – Gas reinjection – 450 bars (6525 psi)

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Experience of Gas Turbines

- Suppliers – GE, Siemens, Solar, Rolls Royce and Hitachi
- Models – GE Frame 7EA, Frame 6, Frame 5, LM2500; Siemens SGT 100, 200, 400 and 800; Rolls Royce – RB211, Solar Saturn, Centaur, Taurus, Mars, Titans
- Developed Long Term Reliability Plan for BP for a global fleet of > 250 gas turbines.
- Carried out failure analysis of five years of operation of a fleet of 70 gas turbine driven equipment of Exxon Mobil in Bass Strait, Australia.
- These initiatives helped to improve availability (machinery uptime) up to 5% and included convincing stakeholders to
  - Extend operating time between water wash cycles by evaluating efficiency for different cycles,
  - reduced number of turbines in operation significantly saving on fuel consumption and maintenance cost.

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GMC Proprietary Software

- Centrifugal Compressors & Turbo-expanders: We have proprietary software to calculate gas properties, compressibility, selection of compressor casing, number of impellers, operating speeds, power consumptions, and provide machinery footprint (estimated dimensions and weights).
- Centrifugal Pumps: We also have proprietary software to calculate power consumption, performance assessment, pumped liquid temperature rise, thrust load estimates to verify selection of thrust bearings etc.
- Gas Turbine: Calculate gas turbine field performance and select turbines for new applications.

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GMC Global Experience across 3 continents

- Lived and Worked in
  - India (10 years),
  - Australia (10 years),
  - Japan (4 years) and
  - UK (7 years)
- Worked for Top Operating companies – IPCL (Reliance) - 5, Exxon-Mobil (1.5), INPEX (Project) (4) and BP (7) – Total 17+ years
- Worked for Top EPC Contractors EIL, L&T-Chiyoda, Worley, Clough Engineering - Total 15+ years

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Operator Upgrades

- Operator costs – Thumb rule

Plant	Fixed cost	Variable cost
New	66.7	33.3
Old	33.3	67.7

- Benchmark vis-à-vis the best in class practices of global Oil & Gas operators
- Undertake opportunistic upgrades to improve plant profits
- Recent example: Upgrade of flow capacity was increased by 60% of each of the 4 LP compressors for BP Azerbaijan is helping to produce additional 35 million barrels of oil between 2016 to 2024. Upgrade cost US$20 million. Additional oil production = $60 per barrel x 35 = 2100 million dollars. See HP Jul 2017 paper.

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Machinery Analysis – Design Stage

Machines are designed for specific process conditions

4-stages of checks and tests:

- Verification of supplier's experience to manufacture and supply similar machines
- Desk top design analyses
- Standard quality control testing during manufacturing cycle
- Specialised testing in the supplier shop to mitigate field risk

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Engineering Review of Supplier's Experience

Experience of multiple suppliers are reviewed

Impeller: Verification of non dimensional values vs flow coefficient

- Mach Number (tip speed/inlet sonic speed)
- Head coefficient (ability to develop pressure)
- Tip speed (stress developed)

Main rotor design verified to

- Predict unbalanced forces
- Ability to dampen the unbalanced forces

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2nd Stage of Machinery Design Analysis

For new designs (step change), desk top design studies are carried out to assess

a. Thermodynamic performance of the machine using Computational Fluid Dynamics (CFD),
b. Finite Element Analysis (FEA) to check parts response to various forces and stresses.
c. Rotor dynamic analyses is carried out of all the process compressors including rotor lateral analysis, Train Torsional and transient condition analysis e.g. short circuit
d. Dry gas seal assessment including utility consumptions, alarms and trips review for safety
e. Lube oil system review for suitability for new operating conditions
f. Journal and thrust bearing design assessment
g. Control system including surge control system review
h. Couplings and driver assessment

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3rd and 4th Final Stage Validation of Machinery Design

In addition to the routine quality control tests (example radiography of welds), customised test can cost upwards of a million dollars and take weeks to conduct. They include:

- PTC 10, Type 1 compressor performance test in the supplier shop,
- Full load string test to verify train rotor behaviour, if possible.
- Field Performance Test

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Angola - Potential flow increase by 32%

	MP COMPRESSOR – GTP FPSO, ANGOLA - RESTAGING					Redesign options	
INPUT	DESCRIPTION	UNIT	2004 MP casing 20 bar case 1st stage	2004 MP casing 20 bar case 2nd stage	Casing Stage pressure ratio	2018 MP 10 bar 1st stage	2018 MP 10 bar case 2nd stage
m	Rated Inlet Mass Flow	Kg/Hr	134146.0	131743.0		100000.0	97000.0
MW_{gas}	Molecular Weight of Gas (Refer gas property calc)	Kg/Kg-mol	21.20	21.00		19.89	19.80
C_{p1}	Specific Heat at cons. pres. of Gas	kJ/Kmol K@15°C	42.09	41.77		40.32	40.18
C_{p2}	Specific Heat at cons. pres. of Gas	kJ/Kmol K@100°C	48.37	47.98		45.75	45.77
P_1 (gas)	Suction Pressure	Kpaa	**1630.0**	**3783.0**	1000.0	**1000.0**	**2500.0**
T_1 (gas)	Suction temperature	Deg. K	307.9	307.9	307.9	307.9	307.9
P_2 (gas)	Discharge Pressure	KPaa	3853.0	8500.0	6600.0	2569.0	6600.0
Z1	For P1, T1 select Z1 Compressibility from charts	Lee-Kesler-Ploecker	0.961	0.912		0.979	0.948
Q1	**Actual inlet flow**	**m^3/hr**	**9549**	**3871**		**12599**	**4755**
Frame	Frame number - refer engg notes		D8R6B	D8R6B		D8R6B	
ηp	Polytropic Efficiency	% / 100	0.850	0.824		0.800	0.800
Nnom	Nominal RPM	RPM	13151	13151		13000	13000
Dnom	Nominal Impeller Diameter	mm	378.0	359.0		378.0	359.0
T_2	**Discharge Temperature °C**		**97.86**	**96.34**		**113.69**	**116.37**
Z_2	For P_2,T_2 select Z_2 Compressibility from chart	Lee-Kesler-Ploecker	0.953	0.898		0.978	0.946
Total Polytropic Head							
H_p	Head developed	KNm/Kg	109.26	97.95		133.45	133.97
Stg_n	Number of stages		3	3		4	4
N_{oper}	Operating RPM	rpm	13145.50	13140.90		12877.44	12902.49
PWR_s	Total shaft power including losses	kW	4886	4435		4726	4602
u	Calculated Impeller Tip speed	m/sec	260.29	247.20		257.30	244.36

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LNG Train 5MMTPA MR Compressor

INPUT	DESCRIPTION	UNIT	GE AGAA LP casing (K02) MR	AGAA MP casing (K03) MR	AGAA HP casing (K04) MR	XXX AGAA LP casing (K02) MR	AGAA MP casing (K03) MR	AGAA HP casing (K04) MR
m	Rated Inlet Mass Flow	Kg/Hr	1160000.0	1160000.0	1160000.0	1160000.0	1160000.0	1159632.0
MW_{gas}	Molecular Weight of Gas (Refer gas property calc)	Kg/Kg-mol	26.29	26.29	26.29	26.29	26.29	26.29
C_p (gas)	Average Specific heat ratio of gas	kJ/Kmol K	50.37	51.50	51.50	50.37	51.50	51.50
P_1 (gas)	Suction Pressure	Kpaa	352.0	2072.0	3682.0	352.0	1801.0	3442.0
T_1 (gas)	Suction temperature	Deg. K	238.5	317.0	317.0	238.5	317.0	317.0
P_2 (gas)	Discharge Pressure	KPaa	2122.0	3700.0	5900.0	1852.0	3500.0	5900.0
Z1	For P1, T1 select Z1	Lee-Kesler-Ploecker	0.963	0.913	0.842	0.963	0.924	0.850
Q1	**Actual inlet flow**	**m^3/hr**	**239239**	**51215**	**26579**	**239239**	**59631**	**28703**
Frame	Frame number - refer engg notes		MCL1404	BCL1003	BCL 804	88M4	60M5	60M4
η_p	Polytropic Efficiency	% / 100	0.860	0.890	0.870	0.869	0.845	0.866
Nnom	Nominal RPM	RPM	3528	3528	3528	3528	3528	3528
Dnom	Nominal Impeller Diameter	mm	1492.0	1060.0	810.0	1410.0	890.0	871.0
r_p	Compression Ratio	P_2/P_1	6.028	1.801	1.606	5.261	1.939	1.718
k	C_p / (C_p - 8.314)		1.198	1.193	1.192	1.198	1.193	1.192
T_2	**Discharge Temperature °C**		**63.69**	**79.70**	**73.12**	**53.93**	**86.74**	**77.64**
Z_2	For P_2,T_2 select Z_2	Lee-Kesler-Ploecker	0.936	0.898	0.829	0.938	0.909	0.835
Za	Average compressibility	(Z1+Z2)/2	0.95	0.91	0.84	0.95	0.92	0.84
k_a	Average Specific heat ratio	same as k	1.198	1.193	1.192	1.198	1.193	1.192
n_a	Average Polytropic Exponent	same as n	1.238	1.222	1.228	1.234	1.236	1.229
H_p	**Head developed**	**KNm/Kg**	**153.59**	**56.36**	**41.46**	**139.92**	**64.84**	**48.08**
Stg_n	**Number of stages**		**4**	**3**	**4**	**4**	**5**	**4**
N_{oper}	**Operating RPM [2]**	**rpm**	**3525.60**	**3419.28**	**3424.82**	**3482.46**	**3510.14**	**3516.19**
PWR_s	**Total shaft power + losses**	**kW**	**58392**	**20704**	**15582**	**52642**	**25088**	**18151**
TOT PWR	**Total power including all stages+10% margin**				**104146.15**			**105468.96**
u	**Calculated Impeller Tip speed =**	**m/sec**	**275.61**	**195.81**	**149.63**	**260.46**	**164.41**	**160.90**
φ	Flow coefficient		0.138	0.085	0.099	0.166	0.163	0.083
V_2	Discharge Volume from last Impeller		56023.39	31637.35	18071.50	62329.97	34902.13	18481.36
Suc Flange	Size of Suction Flange - Diameter	mm	1750.0	800.0	600.0	1650.0	900.0	600.0

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We have experience with plant concept development, FEED, Engineering and Erection / Construction and Operations of Centrifugal Pumps (API 610), Centrifugal Compressors (API 617), Screw Compressors (API 619) and turbines (API 612 steam and API 616 gas turbines).

We can also help with

1. Performance management,
2. Ensure high operational reliability and availability,
3. Capacity Upgrades, and
4. Troubleshooting.

Thank you for your time. Please feel free to contact either of us at:

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