DAIKIN

DEVELOPMENT OF PREMIUM EFFICIENCY CENTRIFUGAL COMPRESSOR FOR MIDDLE EAST DISTRICT COOLING APPLICATIONS

International District Cooling Conference
Dubai, 15th of November 2016

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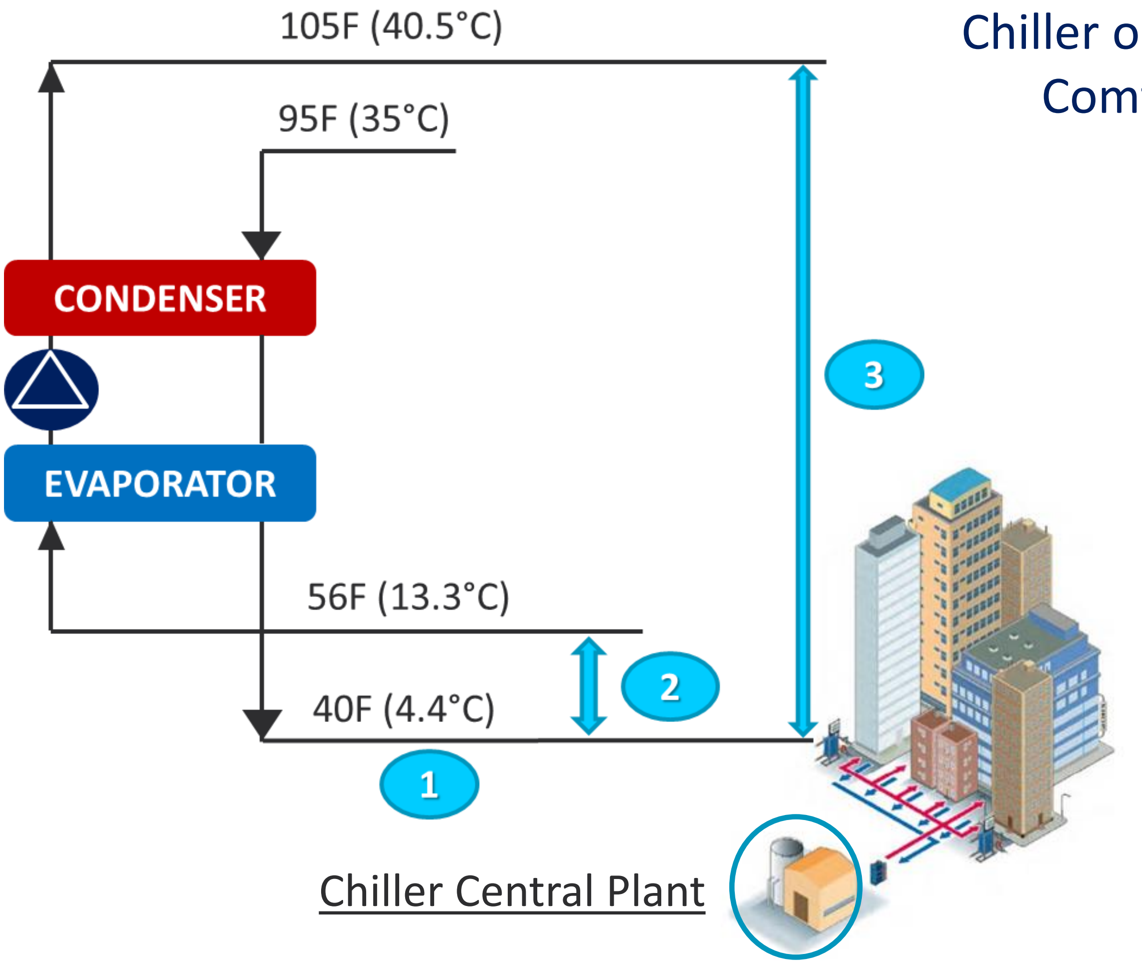
Background

MIDDLE EAST **TYPICAL** DISTRICT COOLING CONDITIONS



Chiller operations - Compared to Standard Comfort Cooling conditions (AHRI):

1

Lower chilled water temperature
to take into account thermal dispersion through distribution piping

2

Higher evaporator water delta-T to reduce water flow rate and system water pressure drops

3

Higher operating lift
(due to higher wet bulb temperature)

MIDDLE EAST TYPICAL DISTRICT COOLING CONDITIONS

District Cooling plants require also chillers the ability to operate at below typical **adverse conditions**:

4

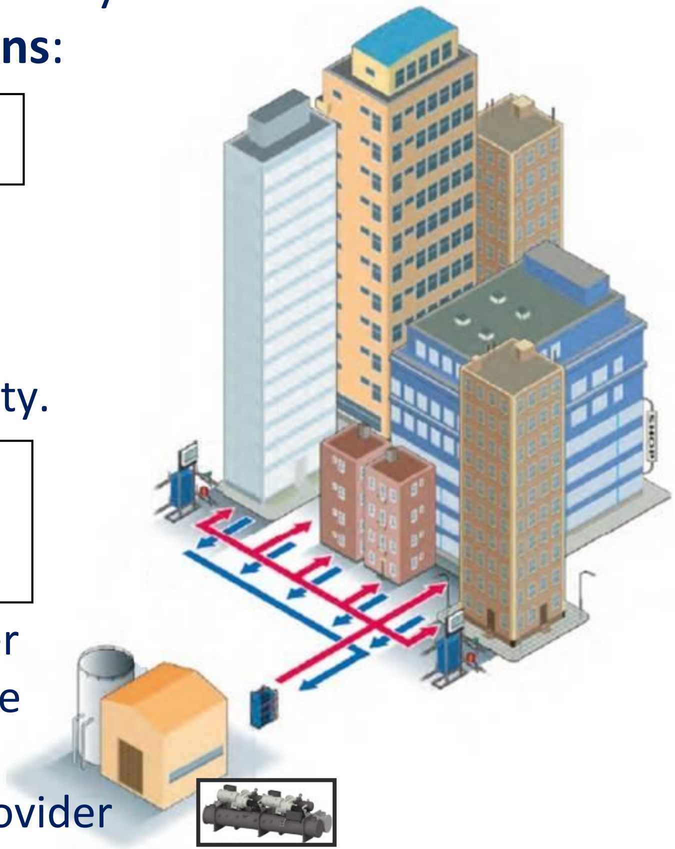
Low delta-T syndrome

- Forces more chillers to operate at part loads;
- Increase in Opex for DC provider since plant efficiency is reduced;
- Impedes full utilization of plant installed capacity.

5

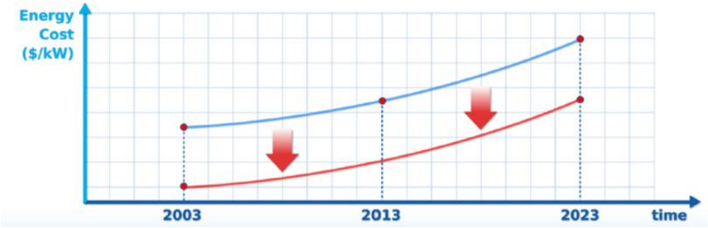
Higher Entering cooling water temperature vs design

- In case of failure of a Cooling Tower, the header temperature of water leaving the tower will rise affecting all the chillers;
- During summer, make-up water from utility provider can be as high as 113F / 45degC

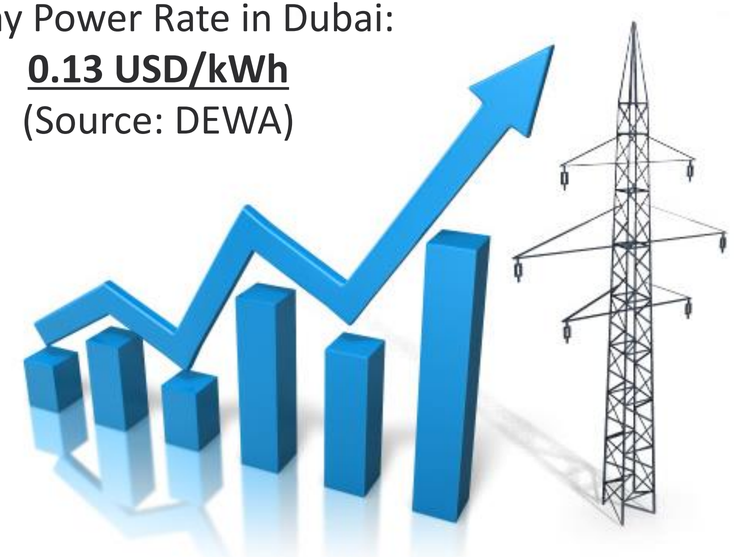


GLOBAL ENERGY MARKET

The **electric energy market price** has been growing in the last years even in the Middle East region and such a **growth** is expected to continue in the next coming years.



Today Power Rate in Dubai:
0.13 USD/kWh
(Source: DEWA)



District Cooling investments must look at future energy cost as well.
As energy demands and costs rise, District Cooling plants for offices, industry and homes need to be **increasingly efficient, reliable and sustainable**

ENVIRONMENT

Most of human activities are based on the use of **equipment** which **impacts the Earth's ecosystem through direct/indirect CO2emissions**.

Demand for natural resources **must not overcome** the Earth's capability to regenerate.

The equipment (incl. HVAC systems) must generate the **lowest possible carbon footprint**, meaning the lowest amount of CO2 emissions.

Several regulations are introducing mandatory and stringent requirements on the **Energy-Related-Products' design** in order to achieve challenging global targets of CO2 reduction in the next decades, as per the agreements from Global Climate Conferences

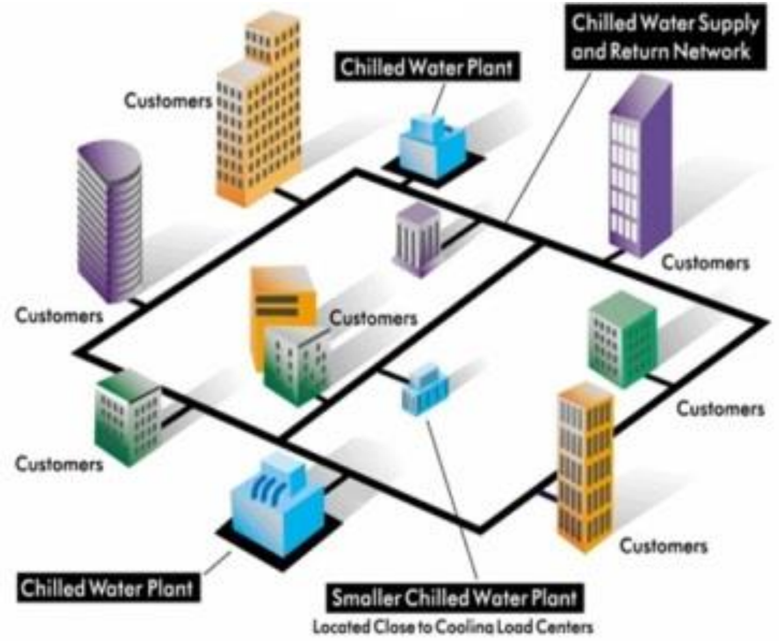
- Latest MOP28 Kigali (Ruanda), October 2016 -

District Cooling case studies

MASDAR CITY

- Masdar City is a Zero-Carbon City under construction in the Emirate of Abu Dhabi (UAE)
- City concept based on renewable energy, environmental sustainability, clean technology and high energy efficiency.

Client: Masdar
Consultant: Domiko
Contractor: ADC Energy Systems



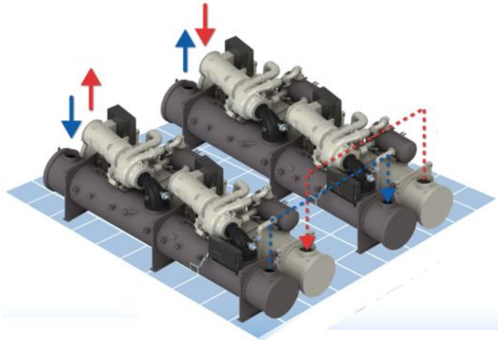
This project is based on a concept of **distributed district cooling.**

Full load and part load efficiencies have been optimized, by also taking benefit from the ability of the chiller to operate at **Variable Primary Flow**.

MASDAR CITY

Project Phase I

2 WCT chillers arranged in series counterflow:



Technical Data at full load:

- Cooling capacity: 6000Tons @ Zero Tolerance
- Evaporator water: 60.6F / 44.6F
- Condenser water: 93F / 107F
- Efficiency: 0.575kW/TR @ Zero Tolerance

Chillers have been tested at Factory Test Facility in presence of the Client, at full and part loads with variable primary flow.

Test Results

MASDAR CITY

PERFORMANCE TESTS							
Test conditions		Design		Measured		Measured Vs Design	
% Load	% Evap Water Flow rate	Capacity (TR)	Efficiency (kW/TR)	Capacity (TR)	Efficiency (kW/TR)	Capacity	kW/TR
100	100	6000	0,575	6127	0,570	+ 2,1%	- 1,0%
75	75	4500	0,569	4546	0,564	+ 0,8%	- 0,9%
50	50	3000	0,662	3016	0,628	+ 0,0%	- 5,1%
30	30	1800	0,646	1966	0,607	+ 2,8%	- 6,1%

OPERABILITY TESTS			
Test conditions			Result
% Load	% Evap Water Flow rate	% Cond Water Flow rate	
50	50	60	Stable operation for 30 minutes
50	60	60	Stable operation for 30 minutes
50	80	60	Stable operation for 30 minutes

Test has fully met the commitment

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MASDAR CITY

RUNNING COSTS

Power rate:
0.13USD/kWh

0.575kW/TR Daikin
Vs 0.650kW/TR typical
premium efficiency

300,000 USD yearly saving

CARBON FOOTPRINT

1200tons of CO2 emissions yearly saved, that would need 2,400 trees planted every year to be compensated.

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AL HAMRA VILLAGE (Ras Al Khaimah-UAE)

1,500Km of pristine beaches, over 1,000 villas and townhouses, nearly 2,500 residential apartments, five hotels, an 18-hole golf course, a marina and a shopping mall.

Project phase IV - 2 parallel WCT chillers/Technical Data:

- Cooling capacity: 2 x 2783Tons @ Zero Tolerance
- Evaporator water: 56F / 40F
- Condenser water: 94F / 102.5F
- Efficiency: 0.624kW/TR @ Zero Tolerance

Client: Al Hamra Real Estate Development
Consultant: DC Pro Engineering
Contractor: Turner & Miller International

PERFORMANCE TESTS (Condenser relief)							
Test conditions		Design		Measured		Measured Vs Design	
% Load	% Evap Water Flow rate	Capacity (TR)	Efficiency (kW/TR)	Capacity (TR)	Efficiency (kW/TR)	Capacity	kW/TR
100	100	2783,0	0,624	2847,7	0,618	+ 2,3%	- 1,0%
75	100	2087,3	0,620	2122,9	0,557	+ 1,7%	- 10,2%
50	100	1391,5	0,445	1400,8	0,418	+ 0,7%	- 6,1%
25	100	695,8	0,662	721,4	0,570	+ 3,7%	- 13,9%

Stadium in Qatar

9 SCF pairs of WCT chillers /Technical Data at full load:

- Cooling capacity: 9 x 5800Tons @ Zero Tolerance
- Evaporator water: 57F / 41F
- Condenser water: 95F / **109F**
- Efficiency: 0.633kW/TR @ Zero Tolerance

PERFORMANCE TESTS (Constant CEWT)							
Test conditions		Design		Measured		Measured Vs Design	
% Load	% Evap Water Flow rate	Capacity (TR)	Efficiency (kW/TR)	Capacity (TR)	Efficiency (kW/TR)	Capacity	kW/TR
100	100	5800,0	0,633	5902,3	0,632	+ 1,8%	0,0%
75	100	4350,0	0,696	4362,5	0,673	+ 0,3%	- 3,3%
50	100	2900,0	0,726	2928,2	0,683	+ 1,0%	- 5,9%
22	100	1276,0	0,636	1295	0,627	+ 1,5%	- 1,4%

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New 3000TR

Centrifugal Compressor

NEW CENTRIFUGAL COMPRESSOR

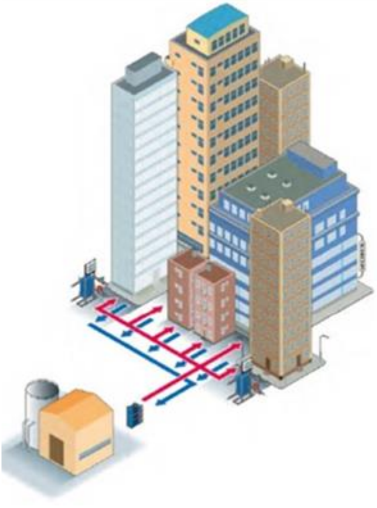
New 3000TR

Centrifugal Compressor

specifically designed for

District Cooling applications

SUITABILITY TO APPLICATION



Capability to provide **reliable and stable operations** at required District Cooling operating conditions

HIGH ENERGY EFFICIENCY

Chiller COP: 0.63kW/TR

@ Zero Tolerance

- Lower running **costs**
- Fast **return of investment**

- **Sustainability**:

  Overall low carbon footprint

«...from cradle to grave»

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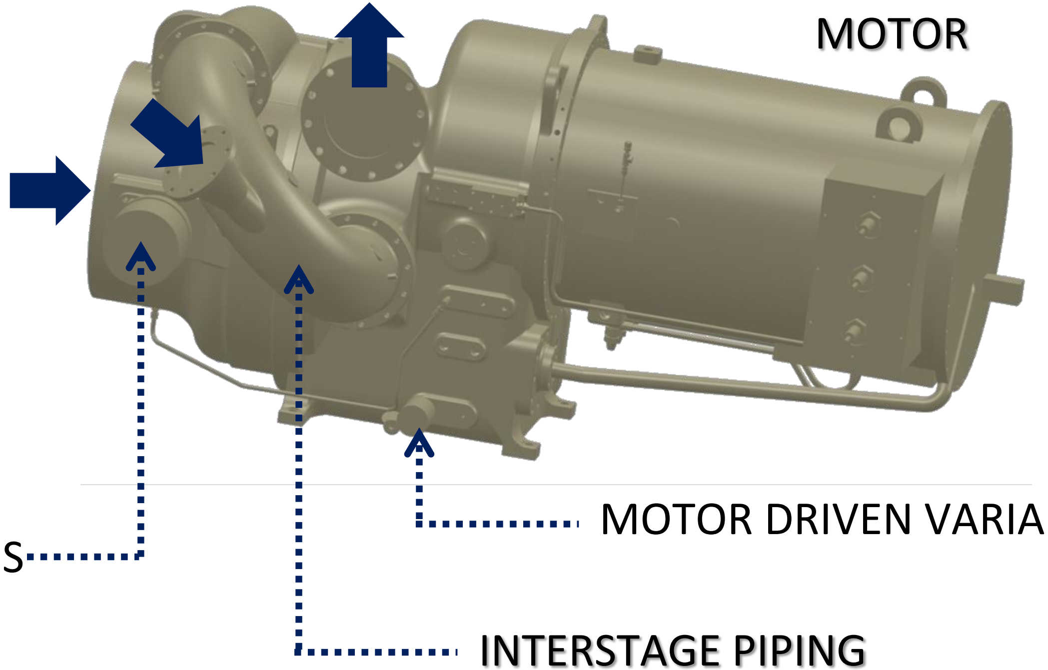
NEW CENTRIFUGAL COMPRESSOR

OVERVIEW



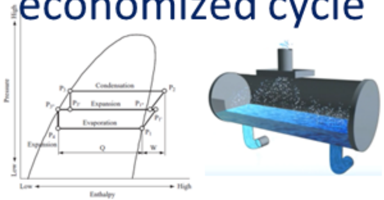
Integral Oil tank with submerged pump to supply lubricating oil

Motor cooling by liquid refrigerant

NEW CENTRIFUGAL COMPRESSOR

FEATURES & BENEFITS

Two stage economized cycle



Back-To-Back Impeller

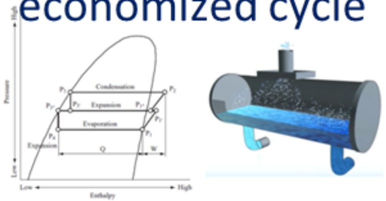
RELIABILITY

Optimized Impeller Geometry

Variable diffuser

STABILITY

Two stage economized cycle



Optimized Impeller Geometry

Variable diffuser

EFFICIENCY & ENVI. IMPACT

Few parts, IGV-DDC moved by electric motor, sleeve bearings, integral oil cooling

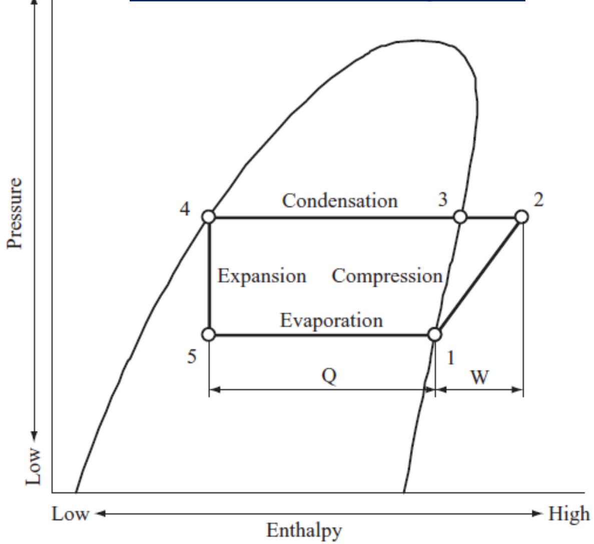
SERVICEABILITY

Compressor

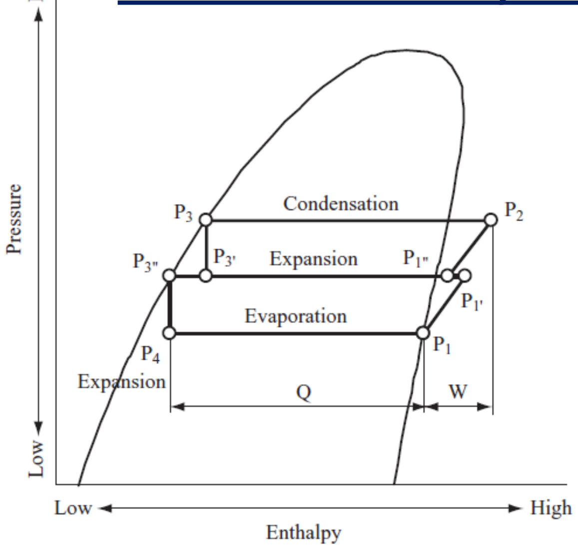
Design features

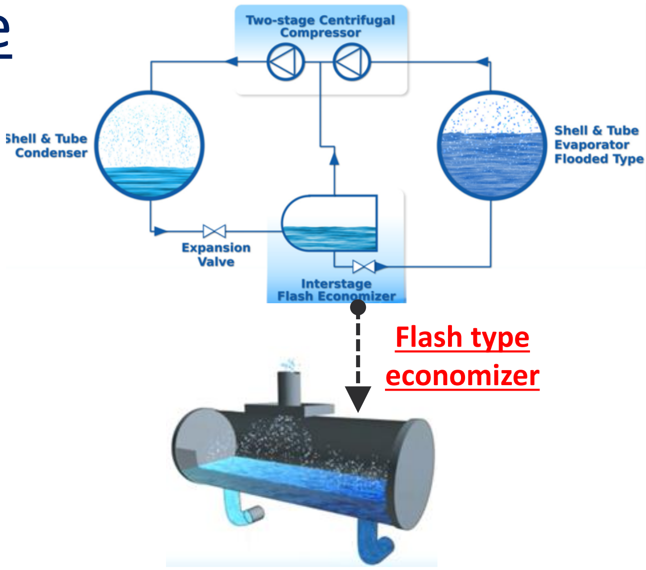
TWO-STAGE ECONOMIZED CYCLE

Standard cycle



Economized cycle

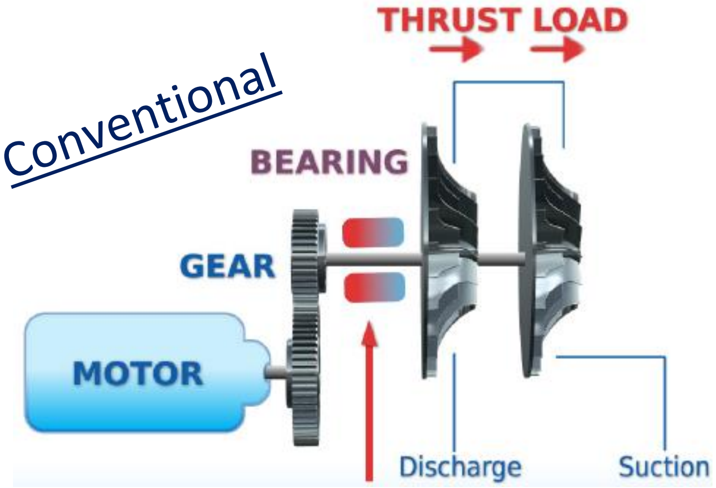




- Under high lift conditions the economizer allows **higher cooling capacity** (up to + 10%) **and efficiency**
- Also **better reliability** and compressor durability thanks to reduced mechanical stress, as the lift is distributed on two impellers.

BACK-TO-BACK IMPELLER

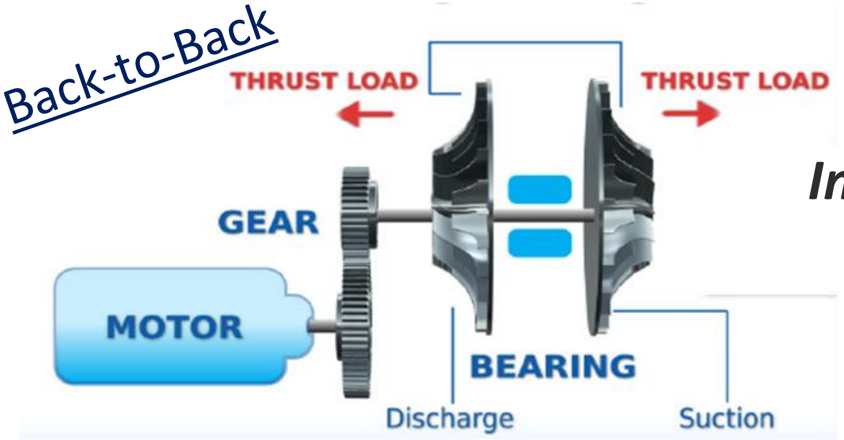
Conventional



Impellers are mounted on same rotating shaft and **oriented to same direction.** The resulting axial load is supported by a thrust bearing.

High bearing stress

Back-to-Back



Impellers are **oriented to opposite directions**. Thrust load reduction by 67%

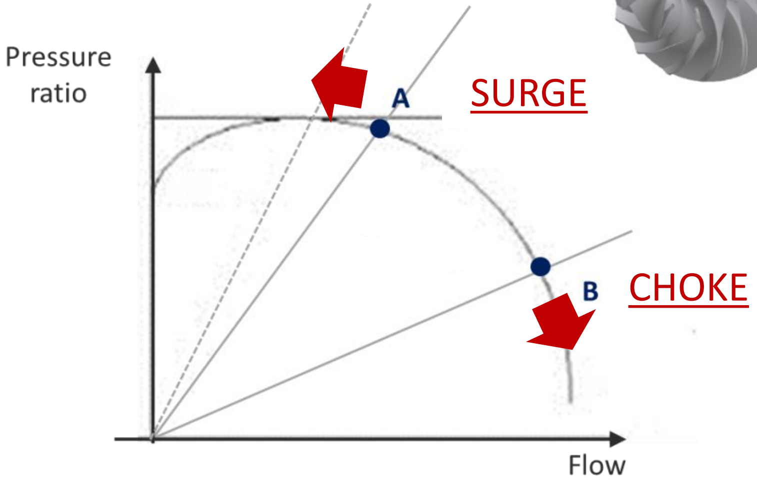
Improved reliability

Lower mechanical losses

Longer bearing life

OPTIMIZATION OF IMPELLER GEOMETRY

Impeller geometry has been optimized in order to **enlarge the compressor stability range** (A-B curve) **and also the efficiency,** thus to grant chiller operations at full and part loads even in adverse conditions.



A-B: stable operations' range

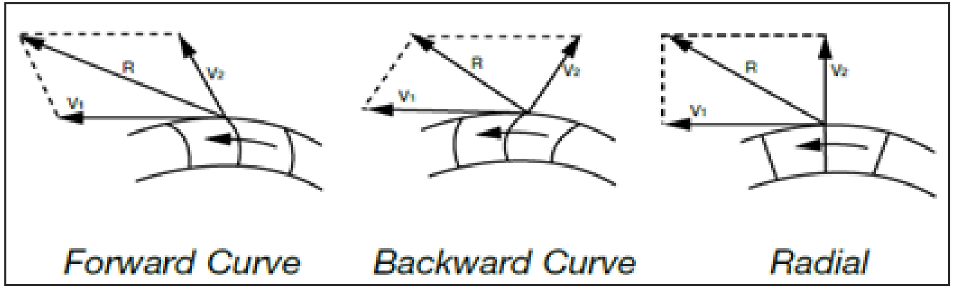
Design items:

- Fully machined impeller with backwards blades
- Outlet blade angle
- Blades number and thickness
- Leading edge geometry

The gas flow has been simulated by **Computational Fluid Dynamics (CFD) codes** for both 1st and 2nd stage and prediction has been then verified with tests conducted on prototypes.

OPTIMIZATION OF IMPELLER GEOMETRY

The impeller is **fully machined** - surface has very low roughness: **+ 2% advantage in efficiency** vs conventional casting.
Blades are **oriented backwards** in order to grant **better efficiency…**

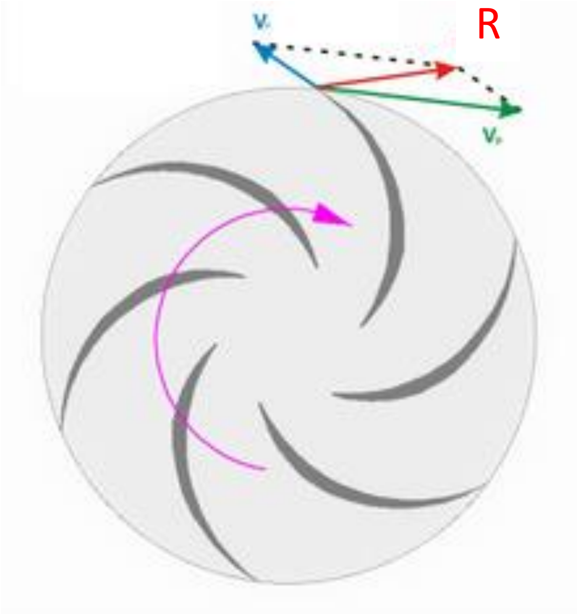


V1: Impeller tip speed **V2**: Radial velocity of gas **R**: Resultant velocity

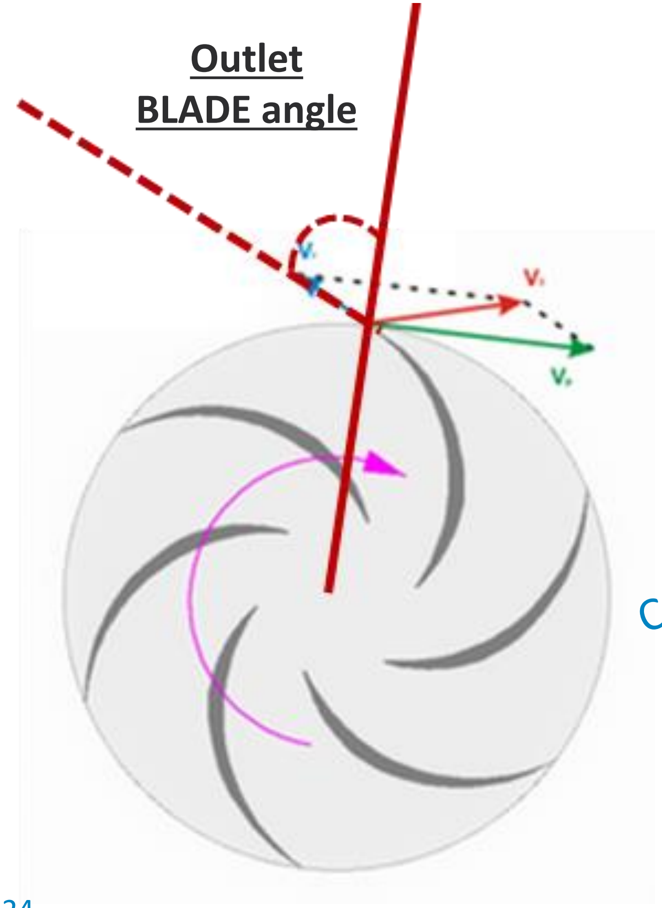
…indeed:

- resultant velocity and friction losses are lower.
- power needed by the impeller is lower

FULLY MACHINED IMPELLER WITH BACKWARDS BLADES



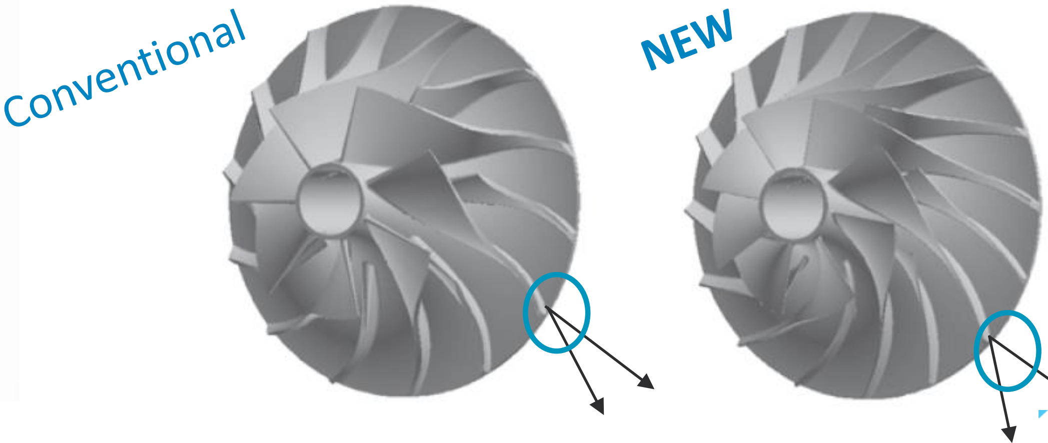
OPTIMIZATION OF IMPELLER GEOMETRY



OUTLET BLADE ANGLE

The **larger** the **impeller outlet blade angle** the **lower** the **min flow at which surge occurs.**

Such an angle has been increased in order to enlarge the compressor stability range vs conventional impeller.

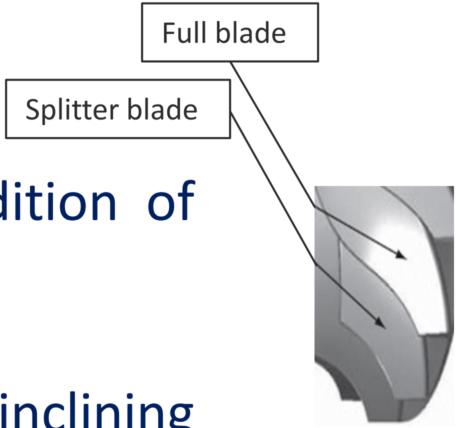


OPTIMIZATION OF IMPELLER GEOMETRY

BLADES NUMBER AND THICKNESS

High nr of blades allows load reduction on each blade, therefore blade thickness can be reduced.

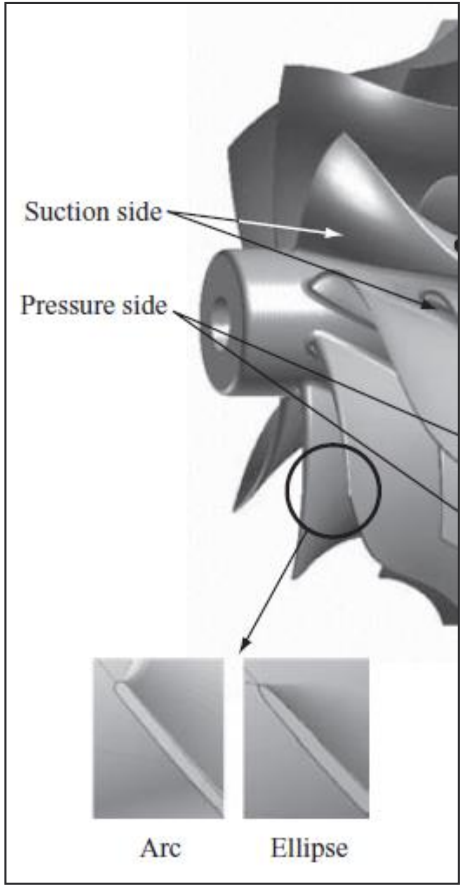
Beneficial effects on efficiency and wider **stability range.**



Compressor design:

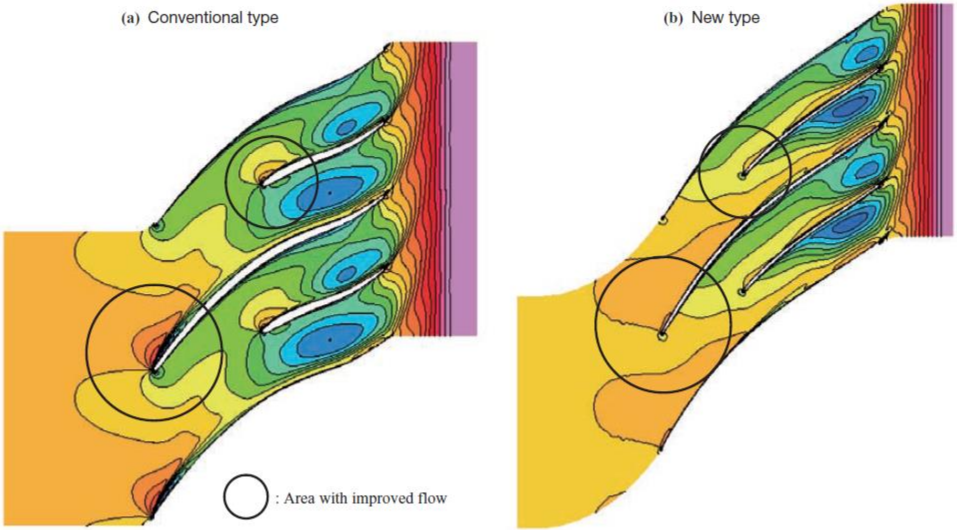
- Total nr of blades has been increased by the addition of intermediate splitter blades.
- Blade thickness has been reduced.
- Length of splitter blades has been increased by inclining them upstream to better drive the gas flow between full and splitter blades.

OPTIMIZATION OF IMPELLER GEOMETRY

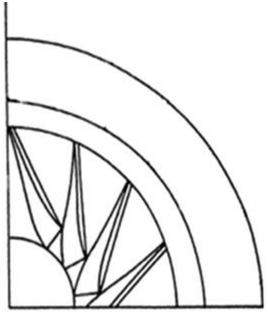


LEADING EDGE GEOMETRY

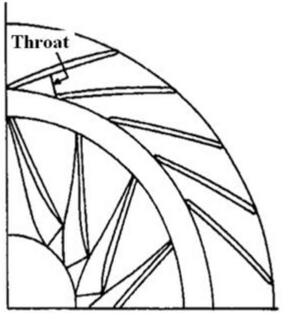
Shape modified **from arc to ellipse** to **improve flow pattern inside the impeller** by suppressing sudden acceleration and deceleration at the edge.



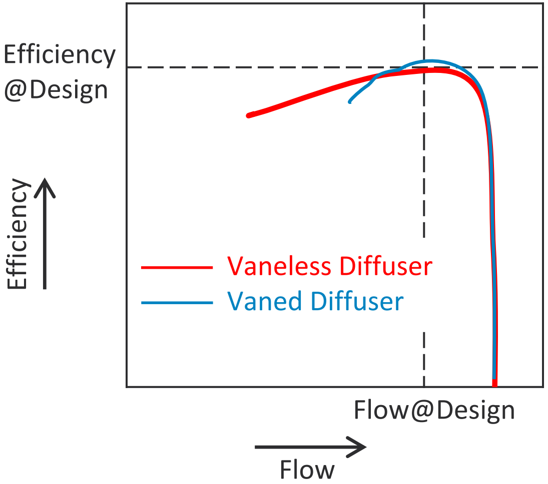
DIFFUSER (VANELESS VS VANED)



Vaneless Diffuser



Vaned Diffuser



Kinetic energy at impeller outlet is converted into pressure energy through the diffuser.

Vaneless diffuser has been selected since allows **wider operating range** and also **good off-design point efficiency.**

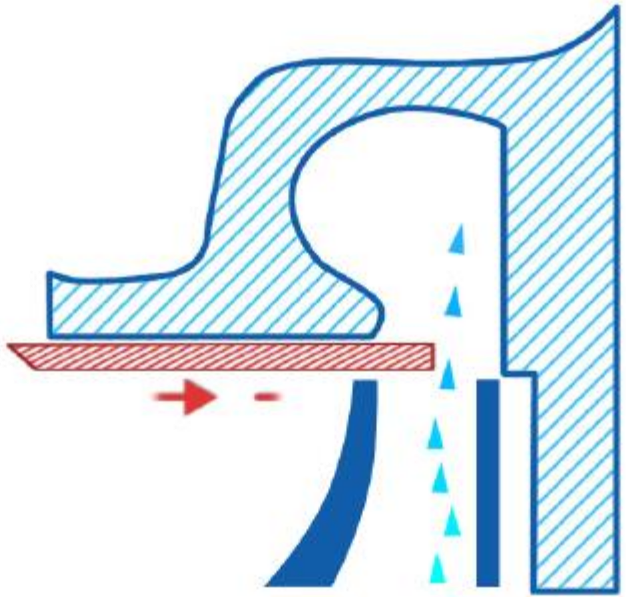
Vaneless diffuser helps also to lower sound level at diffuser.

	Operation Range	Design Point Efficiency	Off- Design Point Efficiency
Vaneless Diffuser	✓	✓	✓
Vaned Diffuser	✗	✓✓	✗

DIFFUSER (DDC = DISCHARGE DIFFUSER CONTROL)

Conventional fixed geometry

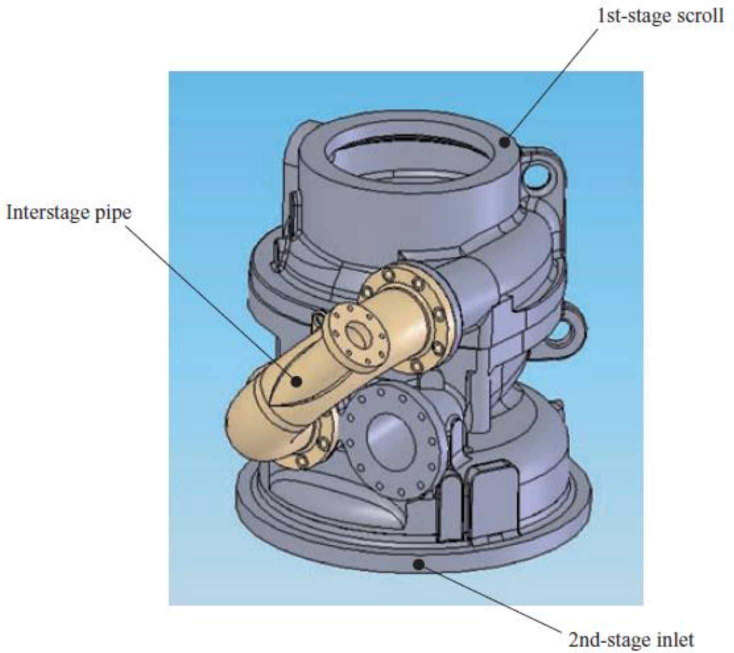
Variable Diffuser



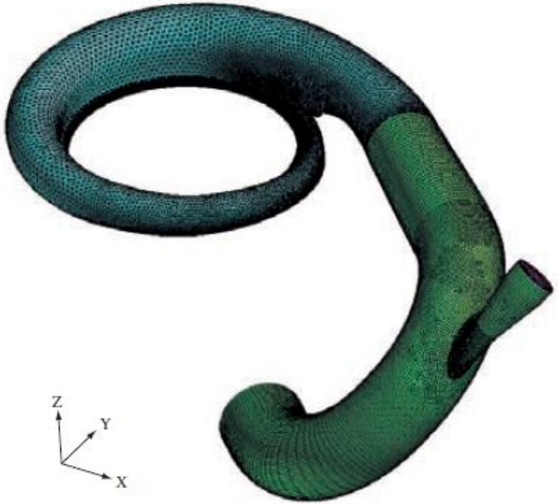
Discharge Diffuser Control avoids surging

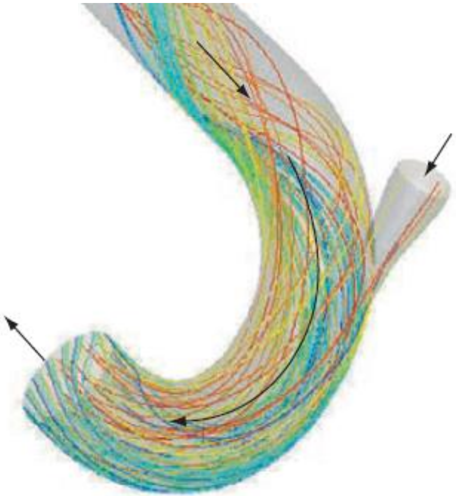
and provides **10% efficiency increase at part loads** vs hot gas by-pass

INTERSTAGE PIPING (ECONOMIZER)



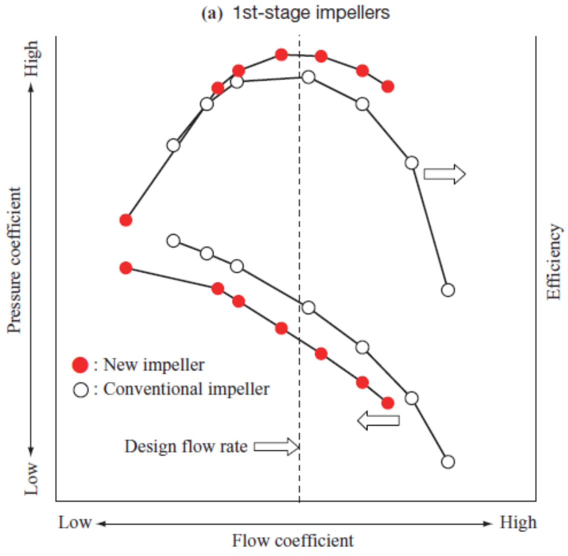
Piping shape has been designed **to avoid any backflow and ensure good mix** of high temperature gas from 1st stage and low temperature gas from economizer in order to prevent any efficiency loss at 2nd stage.

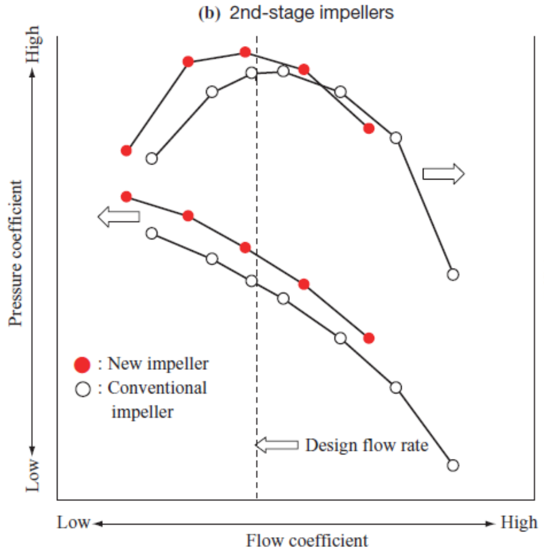


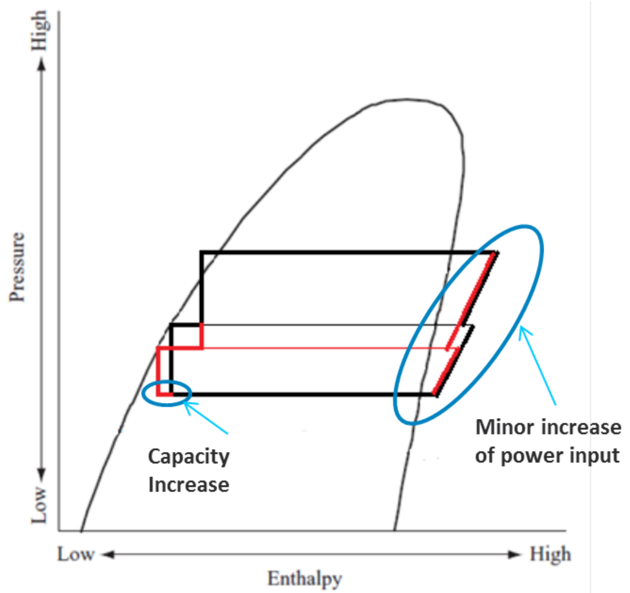


RESULTS - EFFICIENCY

Pressure level between 1st and 2nd stage has been set in order to enhance the economized cycle and overall chiller performance

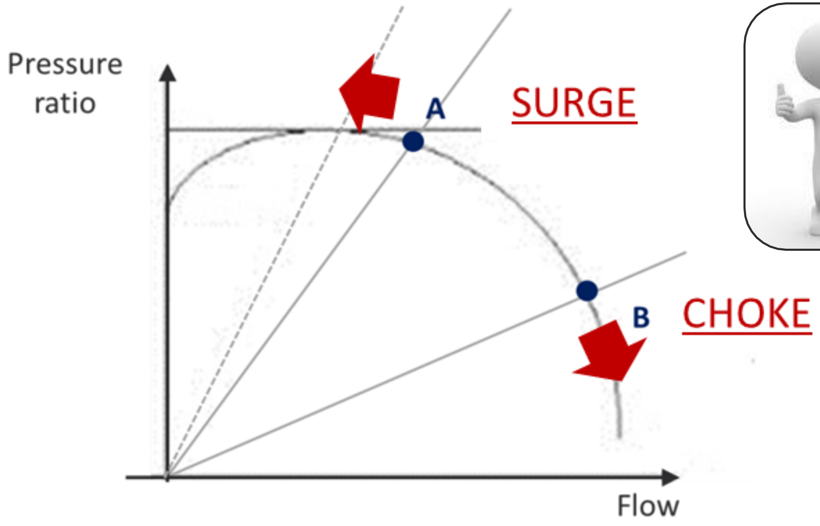




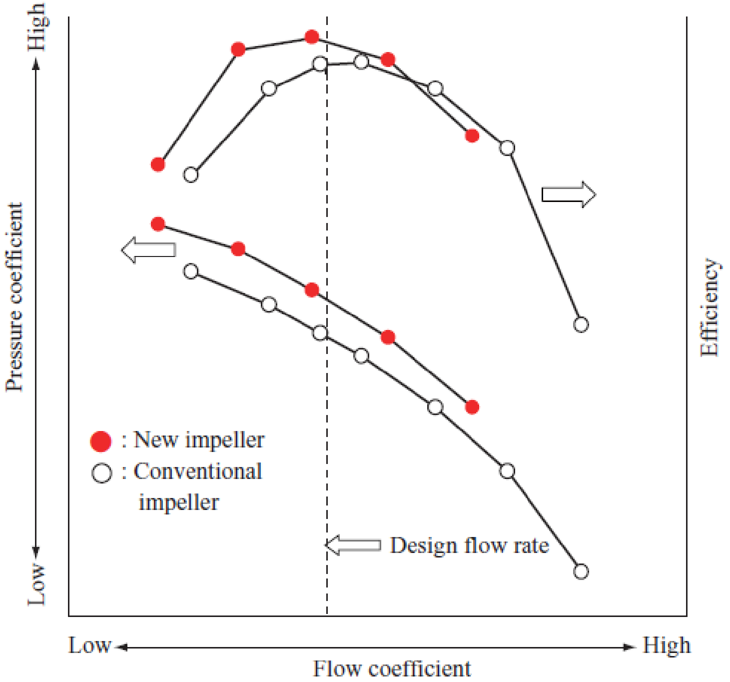


COMPRESSOR DESIGN - CONCLUSIONS

THE GOAL HAS BEEN ACHIEVED!



A-B: stable operations' range



MAX STABILITY VS SURGE/CHOKE: SAFE OPERATIONS ALSO WITH HIGHER CEWT VS DESIGN

OPTIMIZED OVERALL EFFICIENCY-0.63KW/TR @ ME CONDITIONS

From Compressor to Chiller

WCT-series, optimized for District Cooling applications

3000TR Cooling Capacity @ Middle East DC conditions
56/40F
95/105F

0.63kW/TR Zero Tolerance

WCT - Chiller overview

Future-ready (new refrigerants)

MOP 28 – Kigali amendment

HFC Phase-down schedule for Bahrain, India, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia and UAE

2028 to 2031:	100% (base line)	Tons of CO_2 equiv.
2032 to 2036:	90%	
2037 to 2041:	80%	
2042 to 2046:	70%	
2047 and therefore:	15%	

WCT series
- R134a -

- No Phase Out planned for HFCs, incl. R134a. The process requires a gradual reduction of HFCs' consumption.
- Daikin/Daikin Chemicals is also a producer of refrigerants and is working to provide:
  - ✓ Retrofit package for R-134a WCT units already installed
  - ✓ WCT new series, fitted with low GWP refrigerant.

THANK YOU