Dual Power Recovery System for LNG Regasification Plants

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LNG Regasification Process

Liquid Natural Gas is stored at the receiving terminal in insulated tanks at atmospheric pressure and a temperature of 111 deg Kelvin.

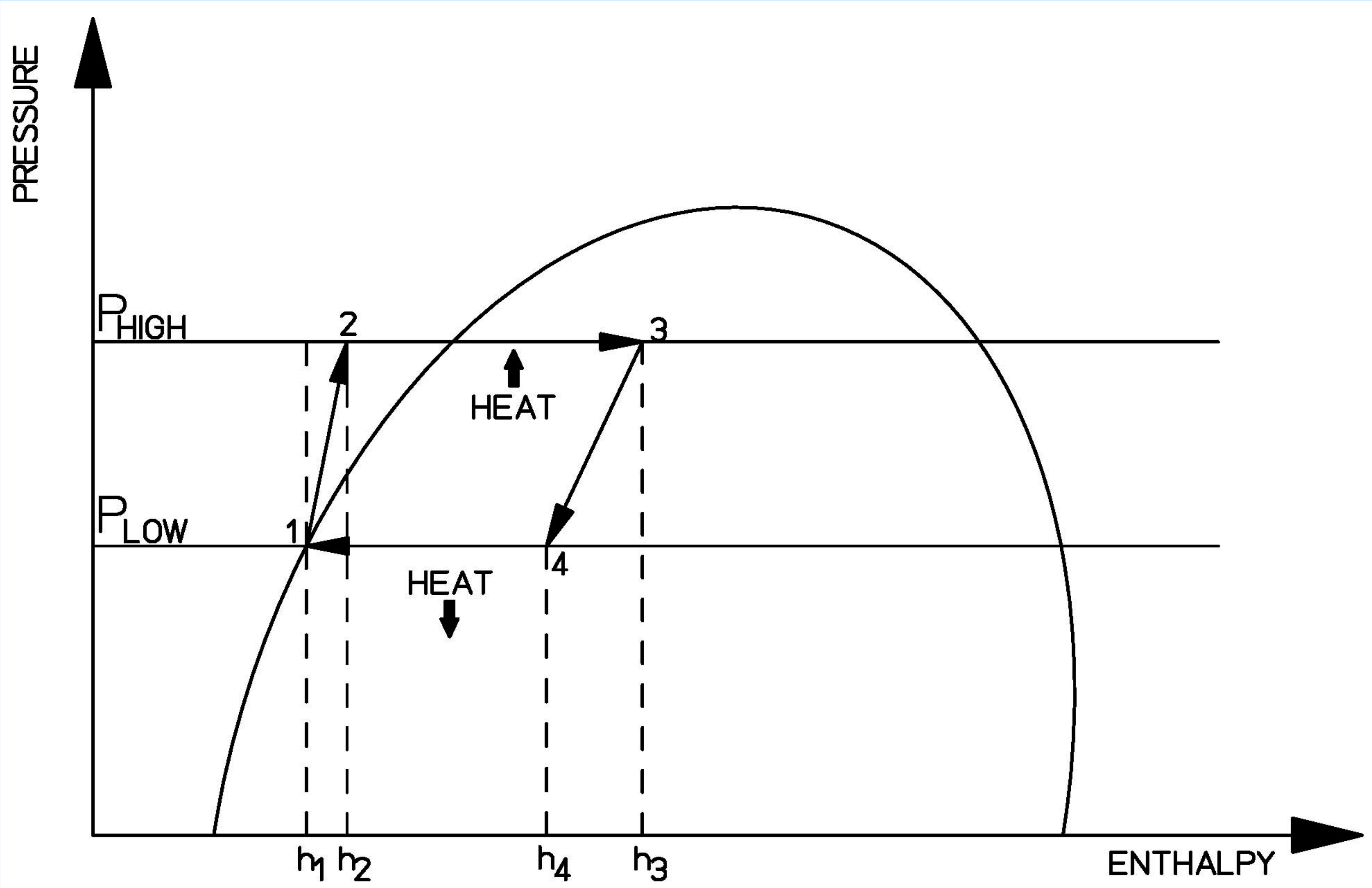
For regasification and distribution the LNG is pumped to high pressure and then heated to vaporize into its gaseous state.

Power Recovery

LNG re-gasification plants are large heat sinks and require also large heat sources.

The differences in temperatures between the heat sources and the heat sinks are in the range of 170 deg Celsius providing the pre-conditions for an efficient power recovery.

The Rankine Cycle is a thermodynamic cycle which converts heat into work. The heat is supplied externally to a closed loop with a particular working fluid, and requires also a heat sink. This cycle generates about 80% of all global electric power.



Thermodynamic Rankine Power Cycle

Schematic Description of Power Cycle

1→2

Pump pressurizes liquefied propane from low to high pressure

2→3

Pressurized Propane is heated by passing through the electrical generator and the heat exchanger

3→4

Pressurized and heated propane expands in a cryogenic expander from high pressure to low pressure

4→1

The expanded two-phase propane condenses in a heat exchanger cooled by the LNG for regasification

Thermodynamic Efficiency of the Rankine Power Cycle

Specific work input to pump: $\mathbf{w_{in} = h_2 - h_1}$

Specific work output from expander: $\mathbf{w_{out} = h_3 - h_4}$

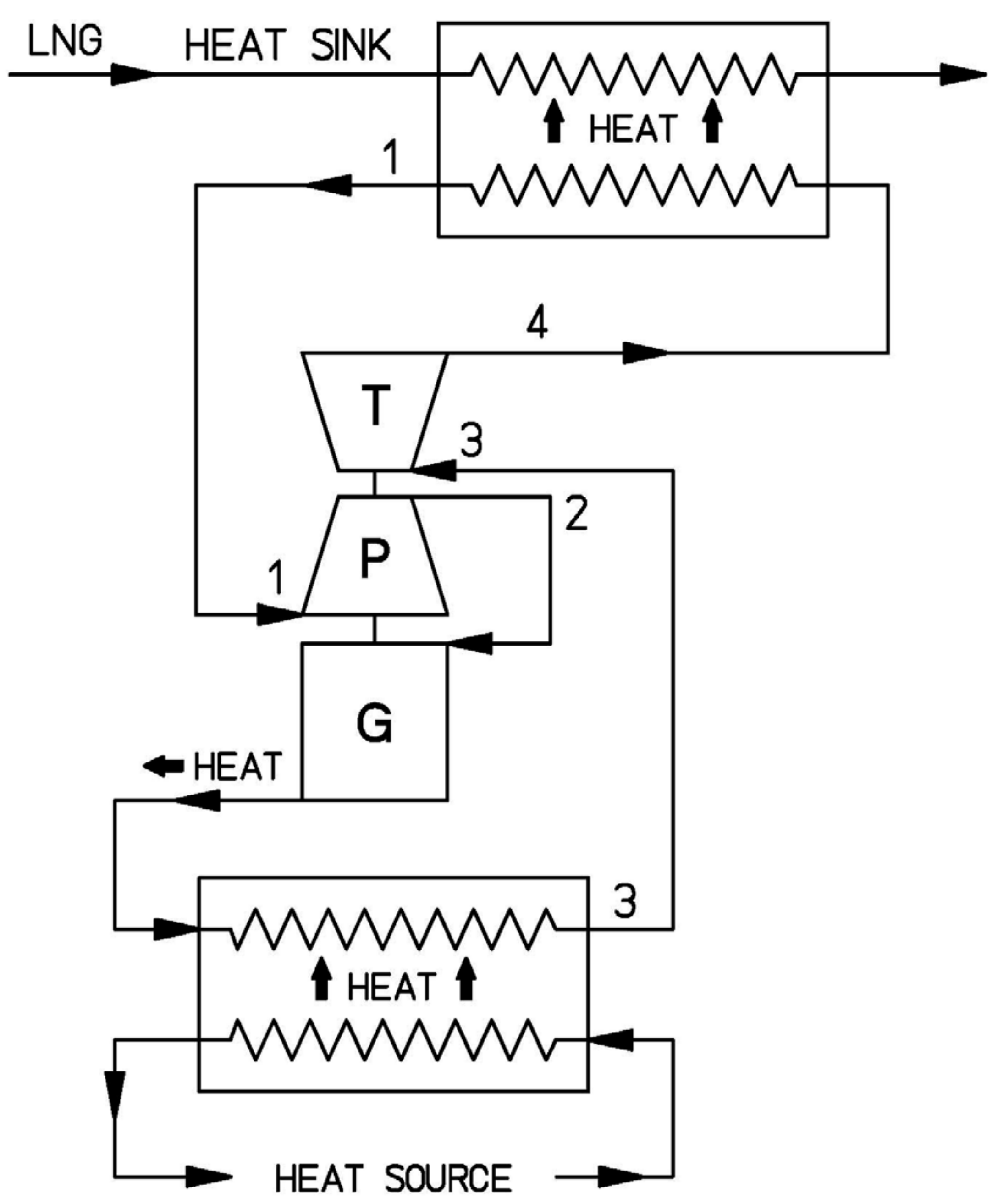
Specific heat input from 2 to 3: $q_{in} = \mathbf{h_3 - h_2}$

Net power output: $\mathbf{w_{net} = w_{out} - w_{in}}$

The thermodynamic efficiency of the ideal cycle is the ratio of net power output to heat input.

$$\eta_{therm} = w_{net} / q_{in}$$

$$\eta_{therm} = 1 - (h_4 - h_1)/(h_3 - h_2)$$



Schematic of the Rankine Cycle with two-phase expansion

Schematic for Power Recovery Using a Cryogenic Working Fluid with a Pump Two-Phase Expander Generator

For the power recovery in LNG re-gasification plants the proposed cryogenic working fluid for the Rankine cycle is a liquefied hydrocarbon gas.

To achieve a higher efficiency the liquefied hydrocarbon gas is passed through two heat exchangers and one set of a pump two-phase expander generator, a compact assembly of a pump, a two-phase expander and an induction generator integrally mounted on one rotating shaft.

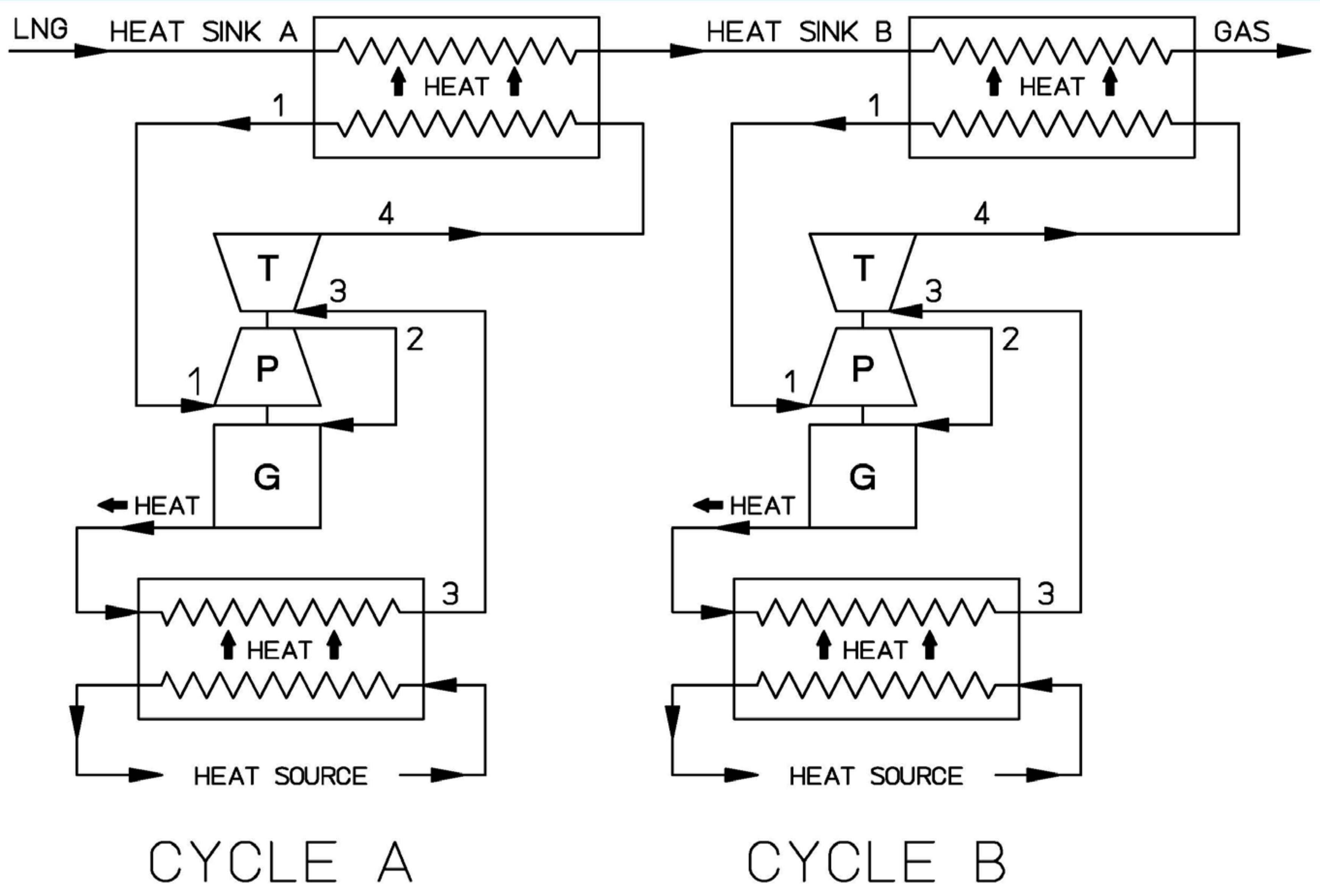
During the process of the regasification, the temperature difference of the LNG between the storage and the gas pipe line is large, approximately 170 Celsius, and it is necessary to install more than one heat exchanger into the system to achieve an efficient overall heat transfer.

Each heat exchanger is optimized for the local temperature range with different working fluids for the best heat transfer at the local temperature.

The individual heat exchangers for the different temperature ranges require then also individual power cycles operating at different pressures and temperatures with different working fluids.

The partition of the power recovery system into smaller power cycles, and in accordance to the temperature increase of the LNG during the regasification process, enables the optimization of the overall power recovery.

With the partition into two power cycles, and assembled in series as a consecutive Dual Rankine Power Cycle A and B, the power recovery system operates with high efficiency and operational flexibility.



Schematic of the Consecutive Dual Rankine Cycle A and B

Schematic for Power Recovery Using a Cryogenic Working Fluid with a Pump Two-Phase Expander Generator

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To achieve a higher efficiency the liquefied hydrocarbon gas is passed through two heat exchangers and one set of a pump two-phase expander generator, a compact assembly of a pump, a two-phase expander and an induction generator integrally mounted on one rotating shaft.

The compact assembly of a

Pump Two-Phase Expander Generator

consists of

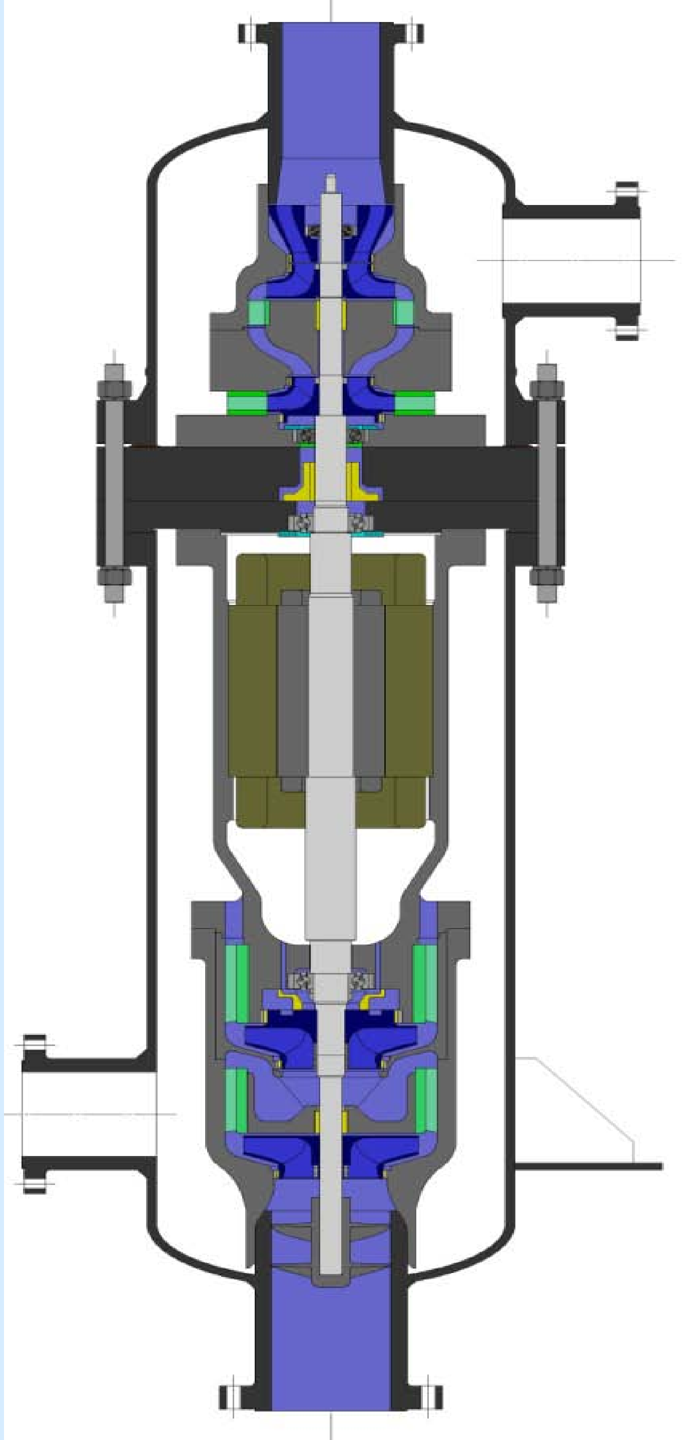
a pump,

a two-phase expander,

and

an induction generator

integrally mounted on one rotating shaft.



Cryogenic Pump Two-Phase Expander Generator

The pressurized fluid passes directly from the pump through the generator housing cooling the generator, then exit to the side and passing through the heat exchanger.

The leakage through the seal and the thrust is minimized due to equal pressure on both sides of the seal and opposing directions of the thrust forces.

Advantages of the compact assembly

The expander work output is larger than the pump work input and the difference in work is converted by the generator into electrical energy.

The losses of a separate pump motor are eliminated.

The losses of the induction generator are recovered and used as heat source to heat the working fluid in addition to the heat from sea water and other heat sources.

Any leakage of the working fluid is within a closed loop and occurs only between pump and expander.

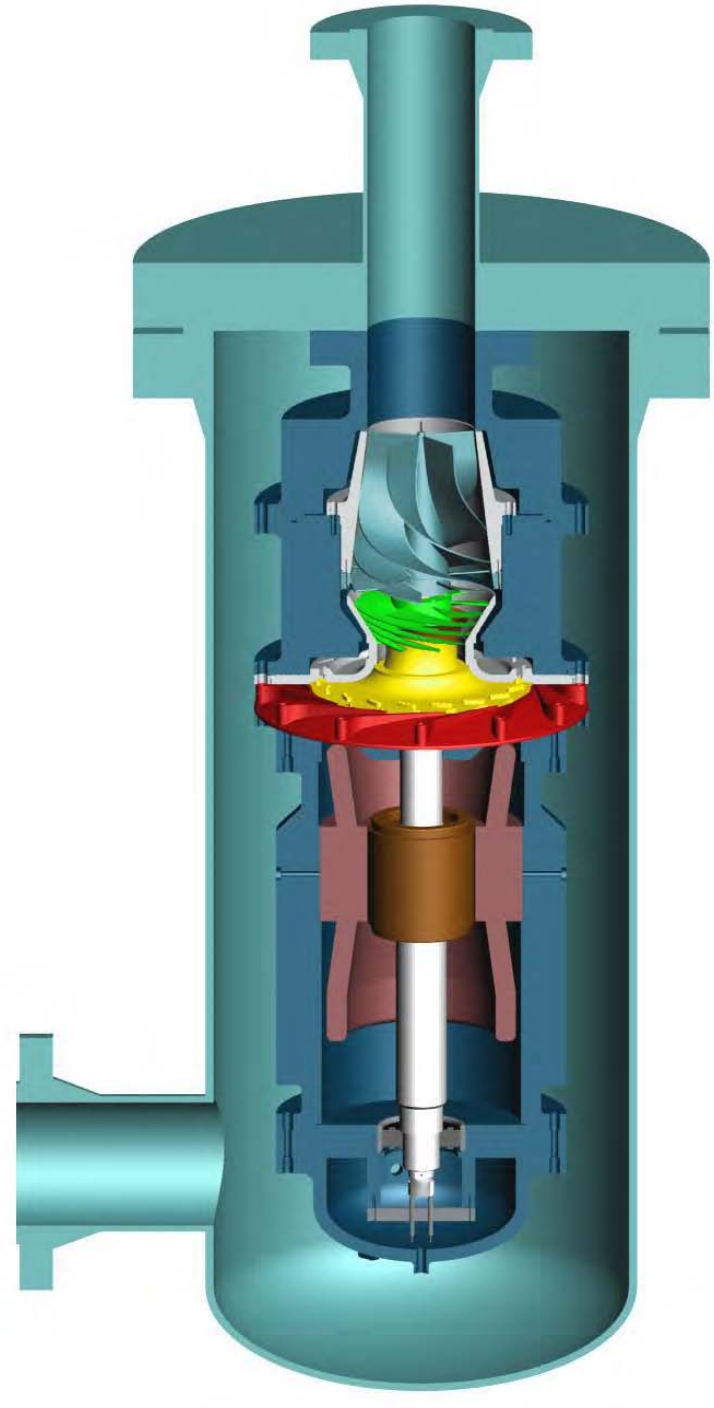
Advantages continued

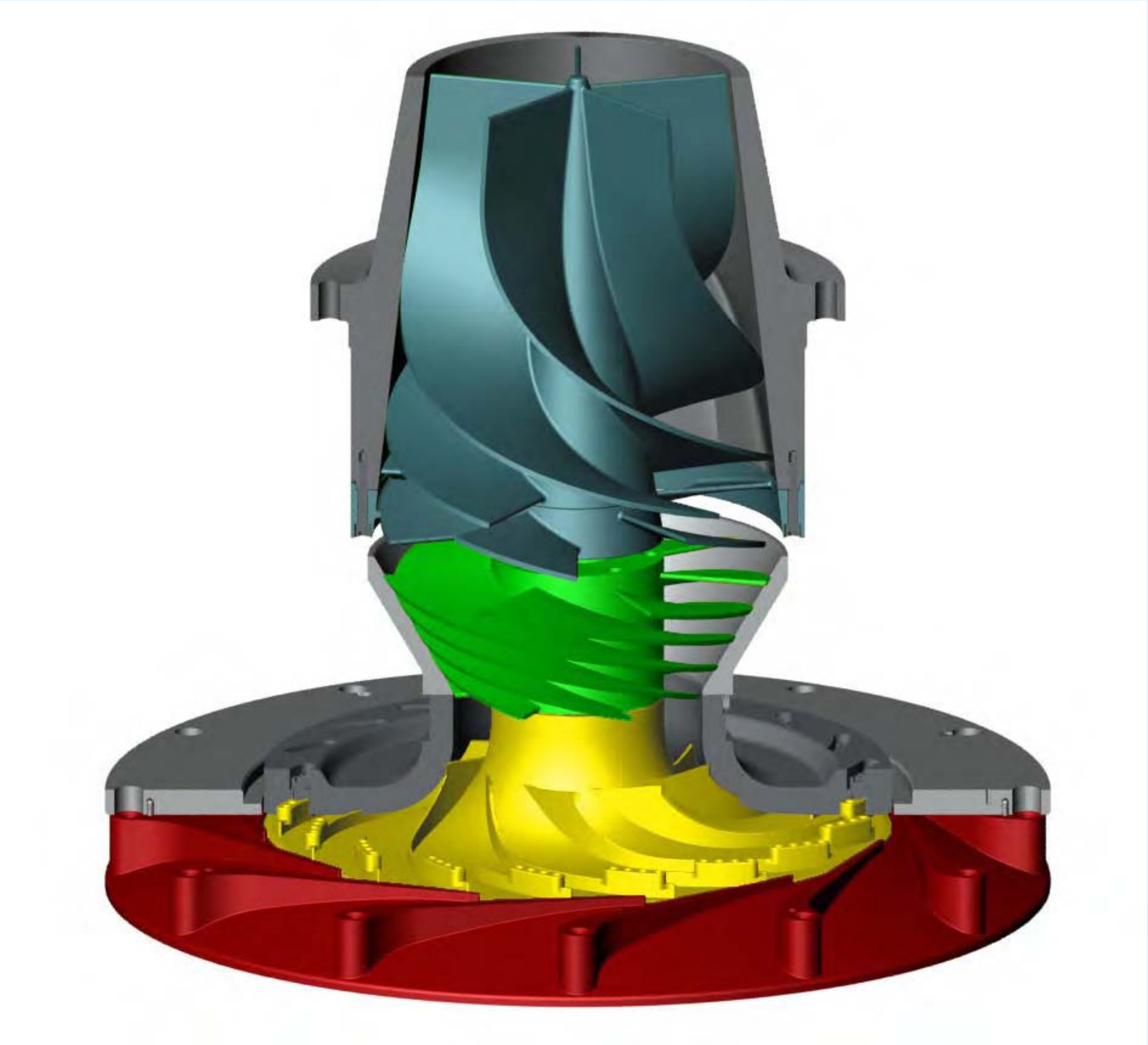
Any leakage of the working fluid is minimized due to equal pressure on both sides of the seal, and small leakages are within a closed loop and occur only between pump, expander and generator.

The axial thrust is minimized due to opposing directions of the thrust forces decreasing the bearing friction and increasing the bearing life.

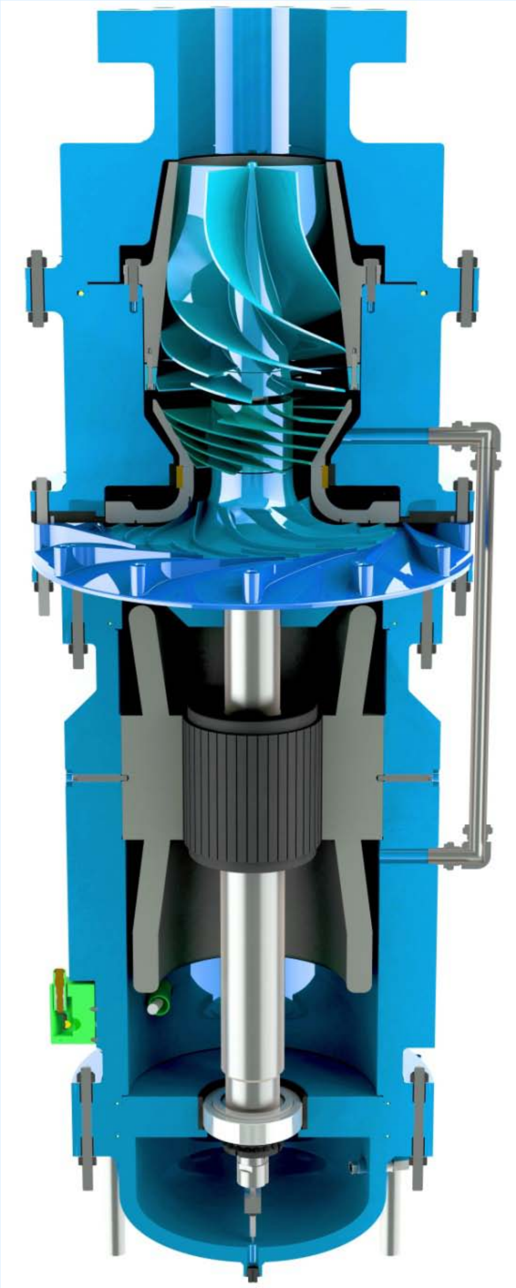
Existing Field Proven Two-Phase Expanders

Cross section of a
Two-Phase
Liquefied Gas Expander
inside pressurized
containment vessel with
lower inlet and
upper outlet nozzle





Hydraulic Assembly for Two-Phase Expansion



Cross section of a Two-Phase Expander with turbine draft tube

to reduce the exit velocity of the rotational vortex fluid flow

←

or to reduce the exit velocity of the axial fluid flow in a diffuser.

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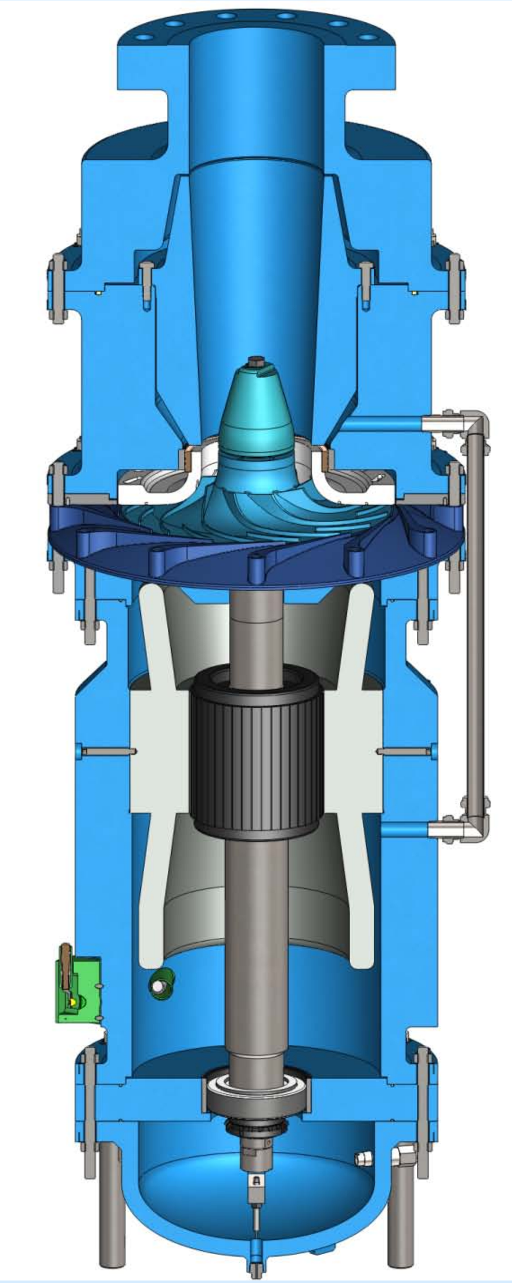
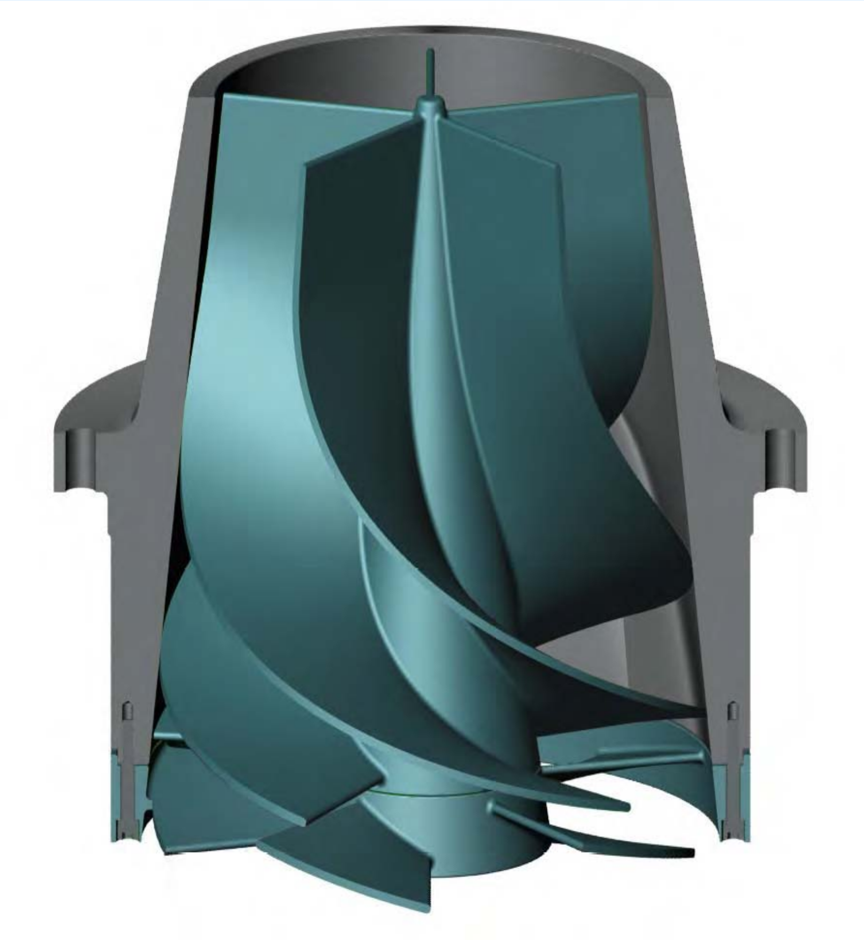


Two-Phase Expander Draft Tube



for pressure recovery

Field Experience with Liquefied Gas Two-Phase Expanders

Two-phase rich liquid feed expanders installed in 2003 are operating successfully at PGNiG, Odalanów, Poland.

Additional four two-phase expanders are installed in the feed to the lower column during 2009.

Two-Phase Liquefied Gas Expander at Ebara Manufacturing

The presented
Dual Rankine Power Cycle,
incorporating a compact design
consisting of a pump, a two-phase
liquefied gas expander and an
induction generator, integrally
mounted on one single rotating shaft,
offers an efficient
and economical power recovery
for LNG re-gasification plants.

Thank You

for

Your Attention