Fifteen Years of Field Experience in LNG Expander Technology

Vinod P. Patel
Chief Technical Advisor
Machinery Technology
KBR
Houston, TX 77002, USA

Hans E. Kimmel
Executive Director
Research and Development
Ebara International Corporation
Sparks, NV 89434, USA

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Hans Kimmel is Executive Director of Research and Development at Ebara International Corporation in Nevada, USA. He holds a Master Degree in Mechanical and Process Engineering and a PhD from Munich, Germany. His main contributions are primarily in the LNG technology

The modern natural gas liquefaction process is based upon the

Linde-Hampson Cycle

independently patented in 1895 by C. von Linde and W. Hampson

In three steps, the process

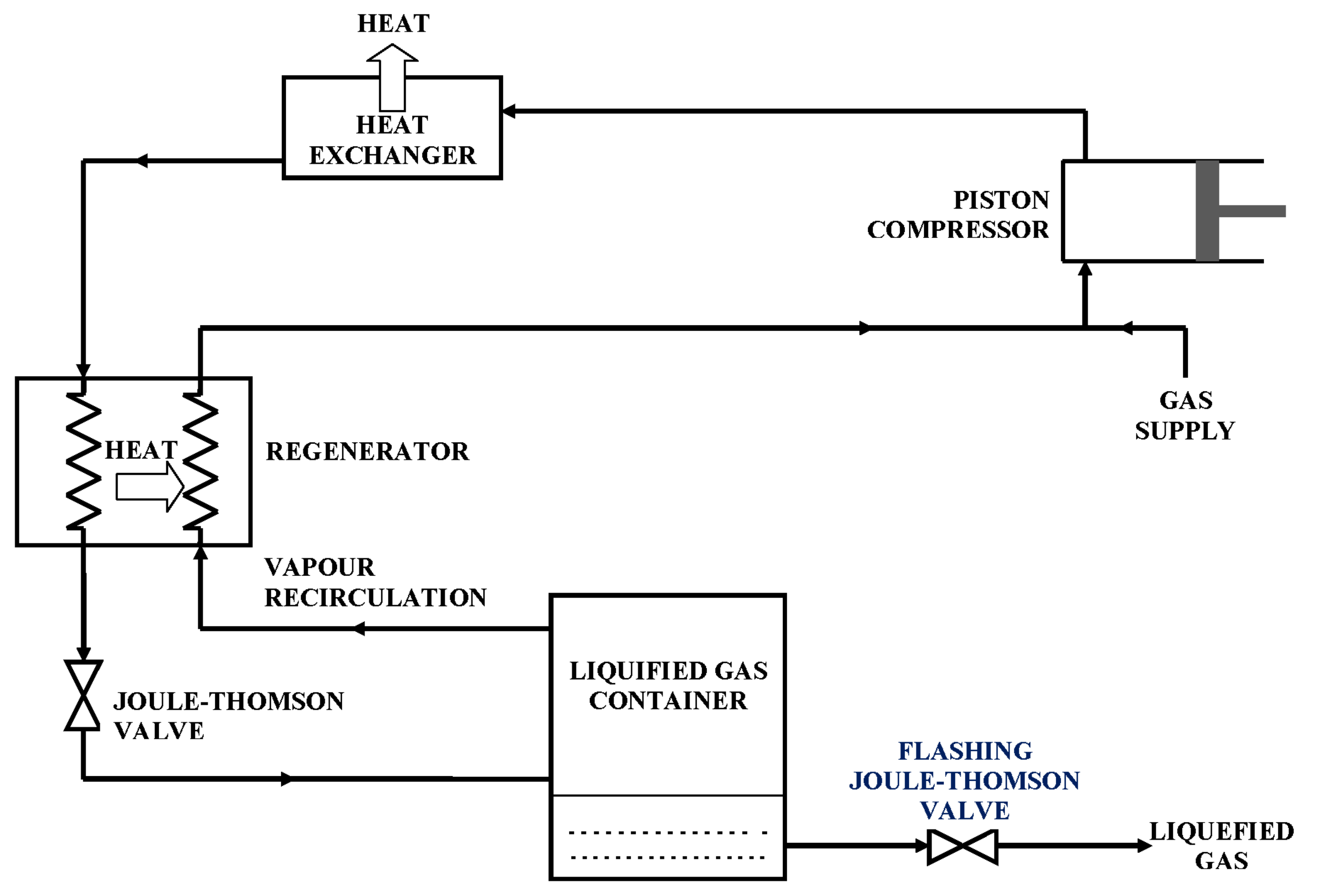
compresses

cools

expands

the gas to a lower temperature

This triple step process is repeated until the gas condenses



Linde-Hampson Air Liquefaction Cycle from 1895

Originally

Compression

was achieved

by a piston compressor

Cooling

by a heat exchanger

Expansion

by a Joule-Thomson Valve

First improvements in operation and efficiency:

Rotary Gas Compressors

and

Rotary Gas Expanders

replaced piston compressors and gas expansion valves

Subsequent improvements

in operation and efficiency:

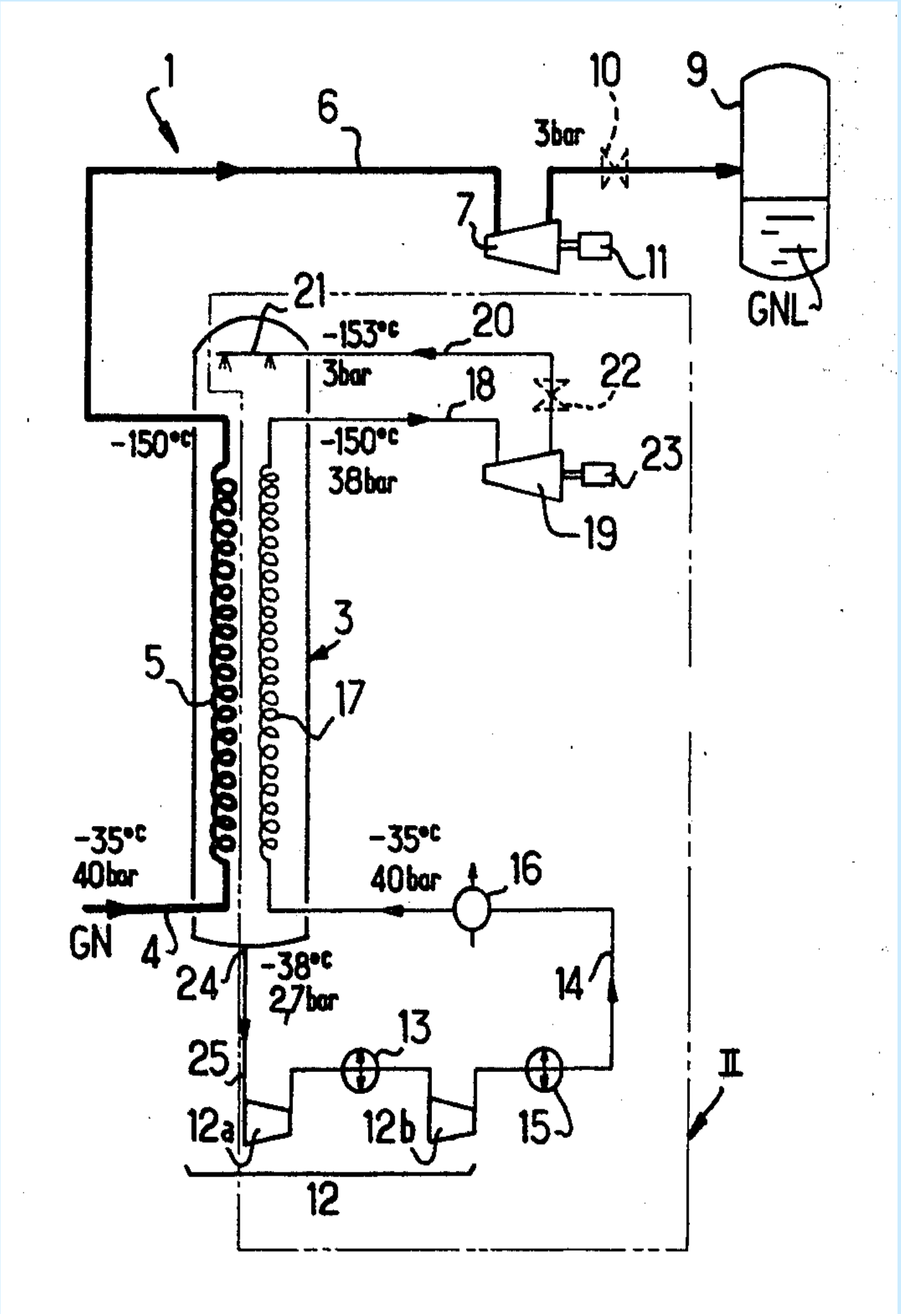
Since 1994

Liquefied Gas Expanders

replace

Joule-Thomson

Liquid Expansion Valves



Henri Paradowski proposed in December 1979 the use of “a cryogenic hydraulic turbine” to improve the efficiency of the liquefaction process

US Patent 4,334,902

It took 15 years from the idea

in 1979 to the first installation

of a cryogenic hydraulic turbine

in 1994 at an LNG Liquefaction Plant in Kansas/USA .

It took another 4 years to install

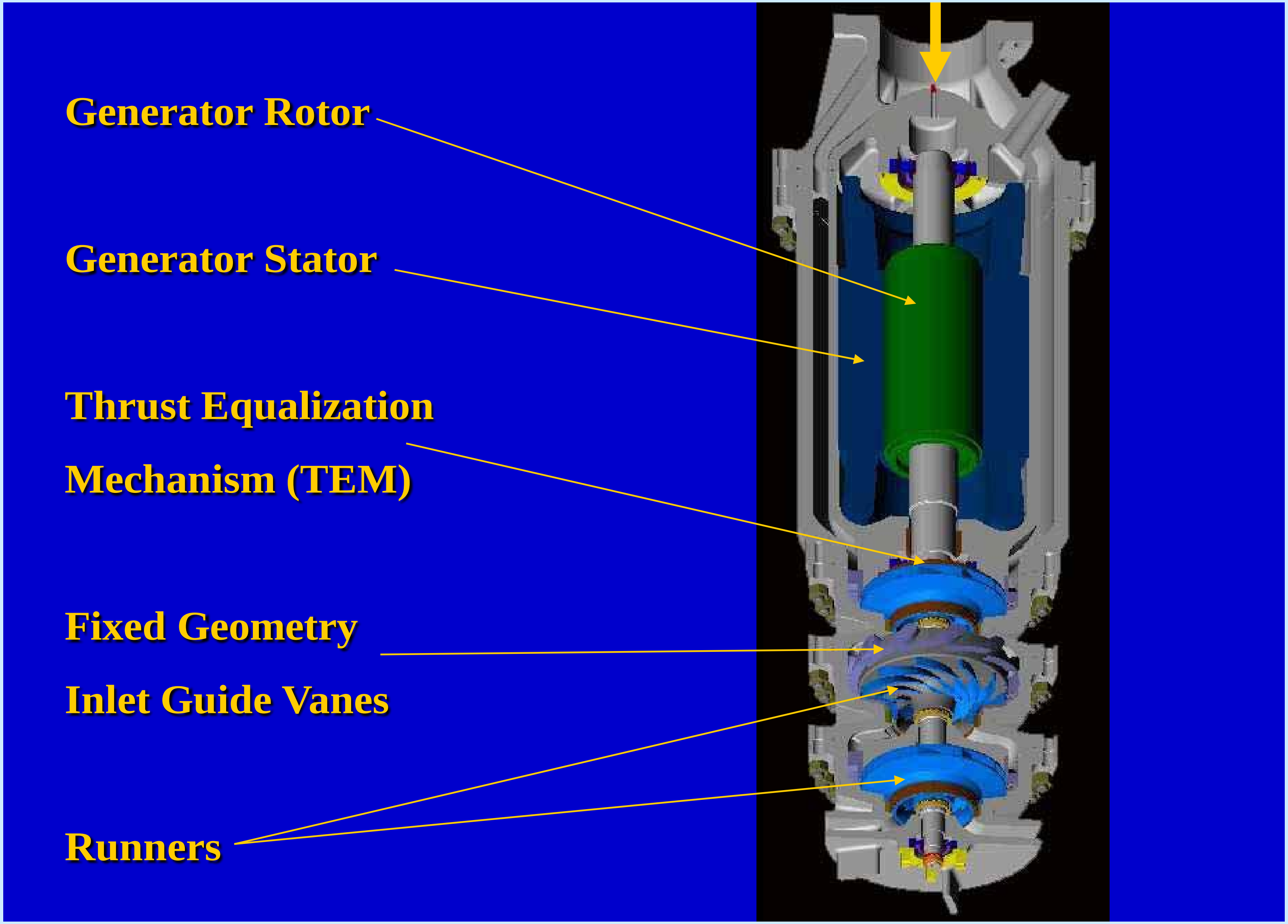
the second one 1998 in Malysia

Early design of an LNG expander with air cooled induction generator, shaft seal and coupling installed 1998 in Malaysia

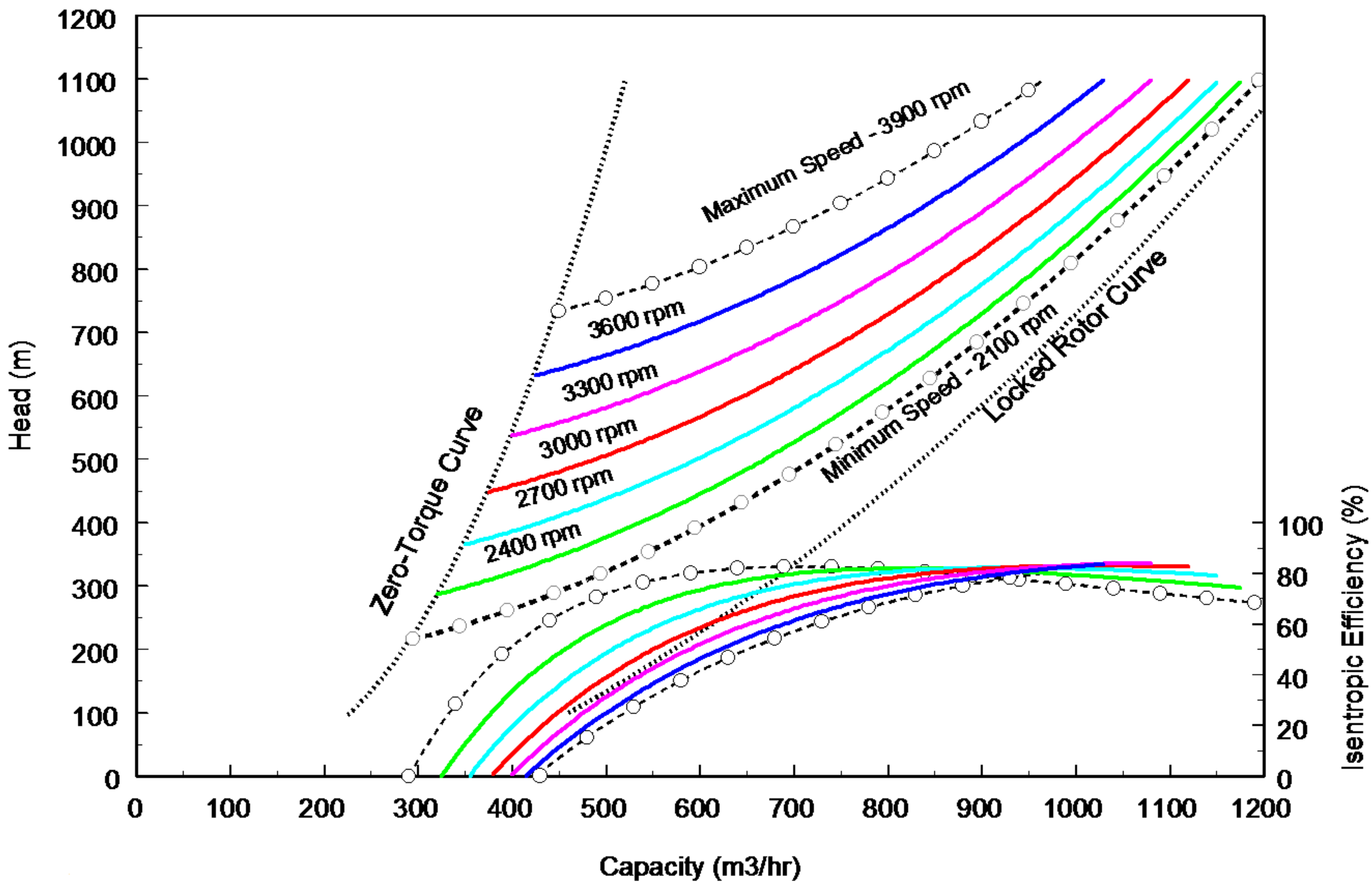
Early design of an MR Propane Mixed Refrigerant expander and an LNG expander installed side by side 1999 in Nigeria

Improved Design

The cryogenic expander operates on variable speed, and is entirely submerged in LNG with no dynamic rotating shaft seals, no coupling between expander and generator, and no thrust bearing, due to a field proven thrust balancing device.

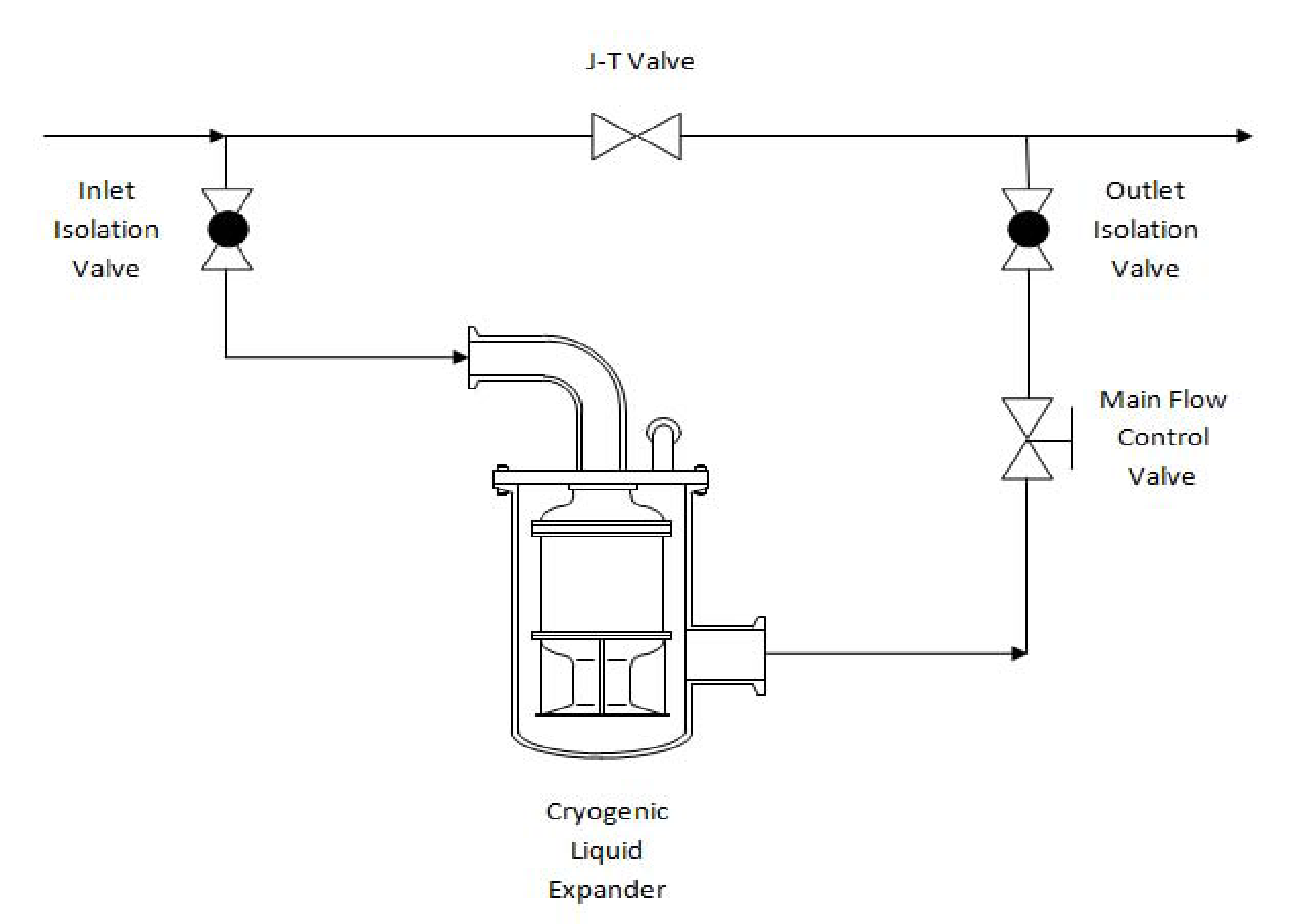


Improved Design with variable speed submerged generator



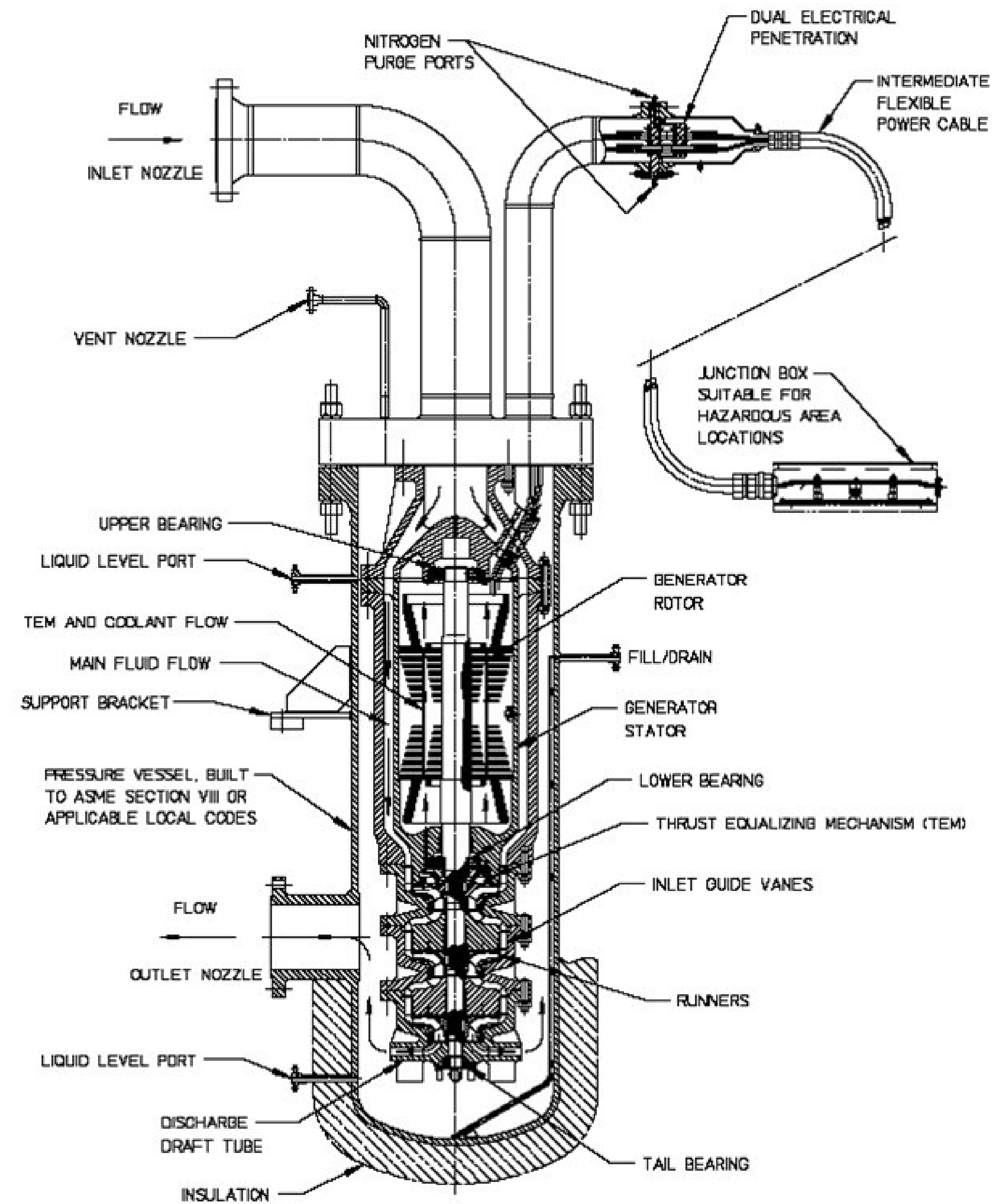
Performance Characteristic of Variable Speed Expanders

First variable speed LNG expander at the LNG test stand in Sparks, Nevada, before shipping to an LNG liquefaction plant in Oman in 1999



Typical Installation Schematic for an LNG Expander

Variable speed LNG expander installed in 2002 in Malaysia

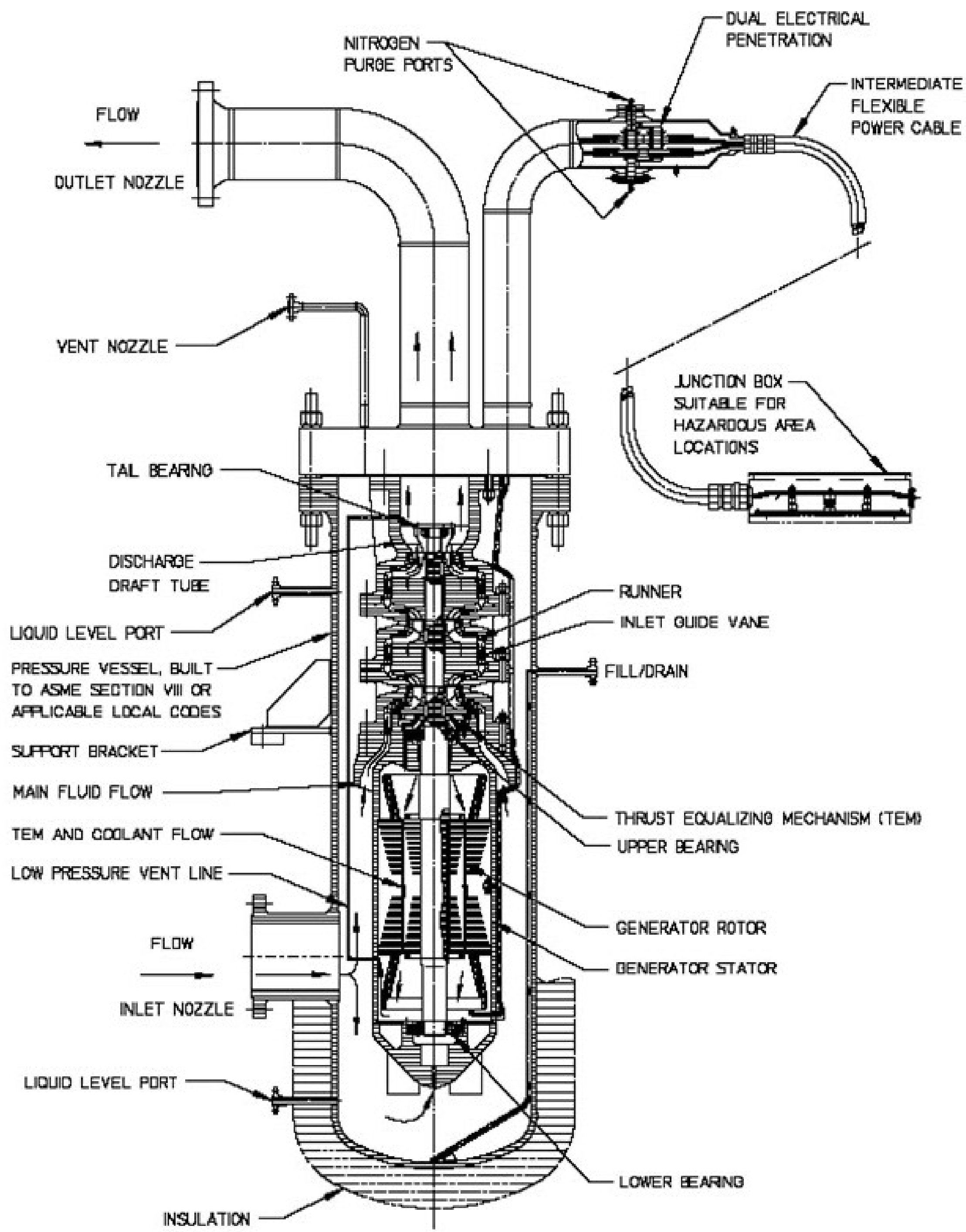


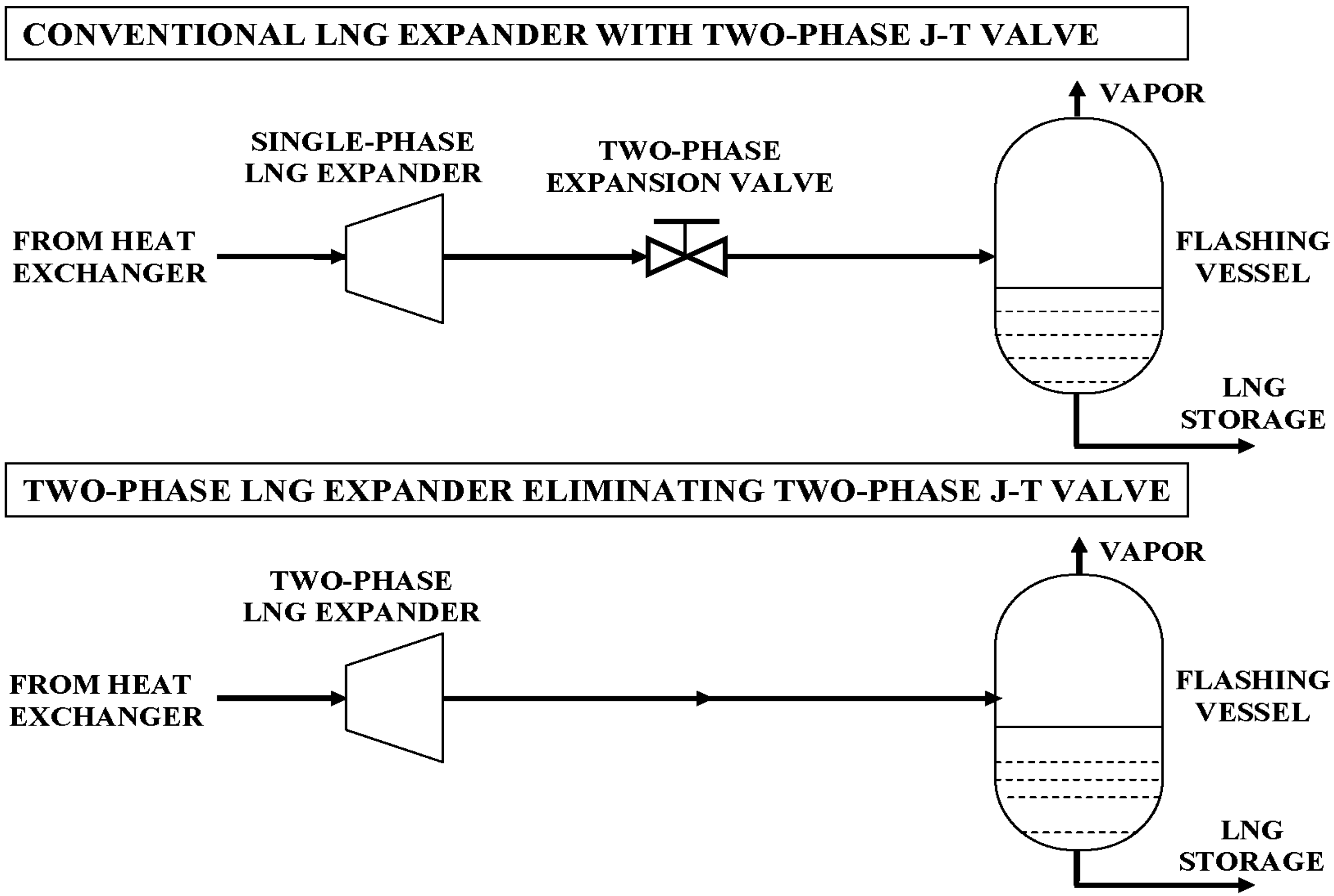
Complete Assembly of an LNG Expander with

Downward Flow Design

Complete Assembly of an LNG Expander with

Upward Flow Design





Conventional Single-Phase versus Two-Phase LNG Expander

Euler Turbine Equation Applied for Two-Phase Expanders

The Euler Turbine Equation states that the generated torque T of rotating turbine runners is equal to the difference of the angular momentum L_1 at the inlet and L_2 at the outlet

$$\boxed{\mathbf{T} = \mathbf{L}_1 - \mathbf{L}_2}$$

The angular momentum **L** is the product of mass flow $\dot{m}$ per time, the tangential velocity **c** of the fluid and the radial distance **r** to the center of rotation.

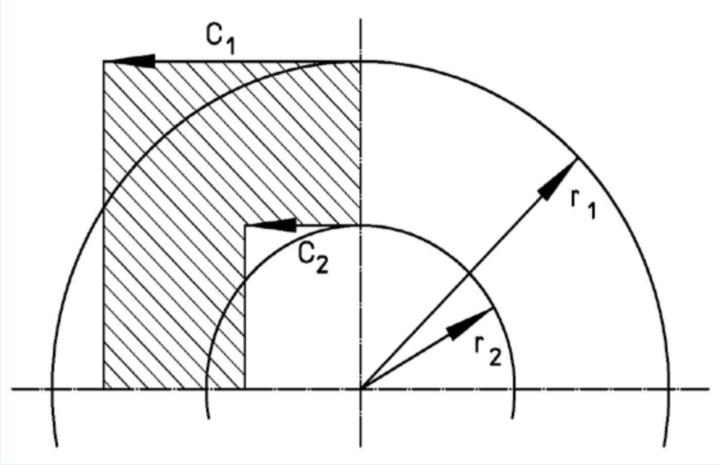
$$\boxed{L = \dot{m}\, c\, r}$$

There are three typical cases for the generated torque T:

Case A: The outlet and inlet momentum L_2 and L_1 are both positive

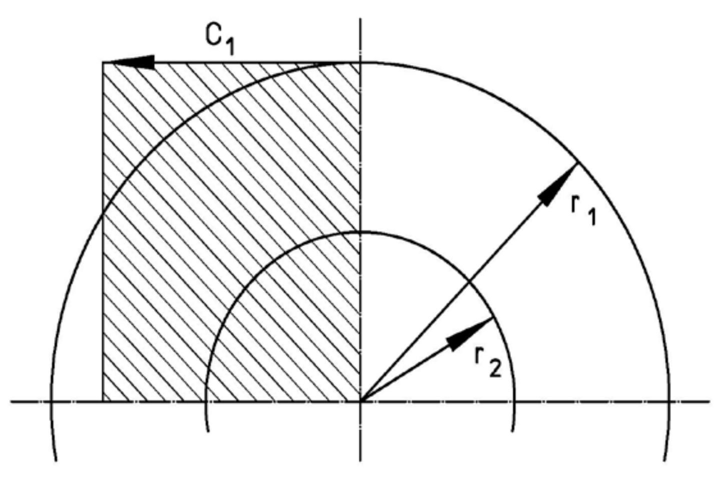
Case B: The outlet momentum is equal to zero

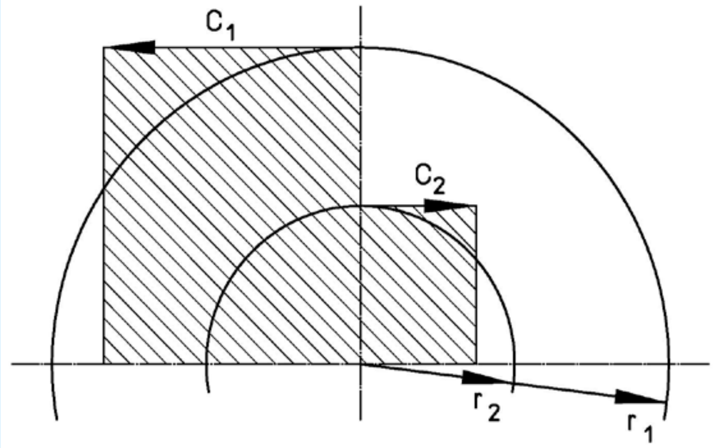
Case C: The outlet momentum L_2 is negative and the inlet momentum L_1 is positive



$$T_A = \dot{m}(c_1\, r_1 - c_2\, r_2)$$

$$T_B = \dot{m}(c_1\, r_1)$$





$$T_C = \dot{m}(c_1\, r_1 + c_2\, r_2)$$

The torque in case C is always larger than the torque in the cases B and A

$$T_C > T_B > T_A$$

The hydraulic efficiency η in case B is always larger than the hydraulic efficiency in the cases A and C

$$\eta_B > [\eta_A ; \eta_C]$$

$$\eta = \frac{\text{Hydraulic Power Out}}{\text{Hydraulic Power In}}$$

The hydraulic efficiency η in case B is at the maximum value, because there is no remaining angular momentum at the outlet and the rotational kinetic energy of the fluid at the outlet is zero.

The generated torque in case C is larger than in case A or case B due to the negative angular momentum at the outlet.

The hydraulic efficiency in case C is smaller than in case B due to the remaining angular momentum at the outlet and the remaining rotational kinetic energy of the fluid at the outlet.

The equation for the mechanical expansion power of two-phase fluids

The specific volume v of saturated fluids is a function of the specific enthalpy h and the pressure p

$$\boxed{\mathbf{v} = \mathbf{v}[\mathbf{h}, \mathbf{p}]}$$

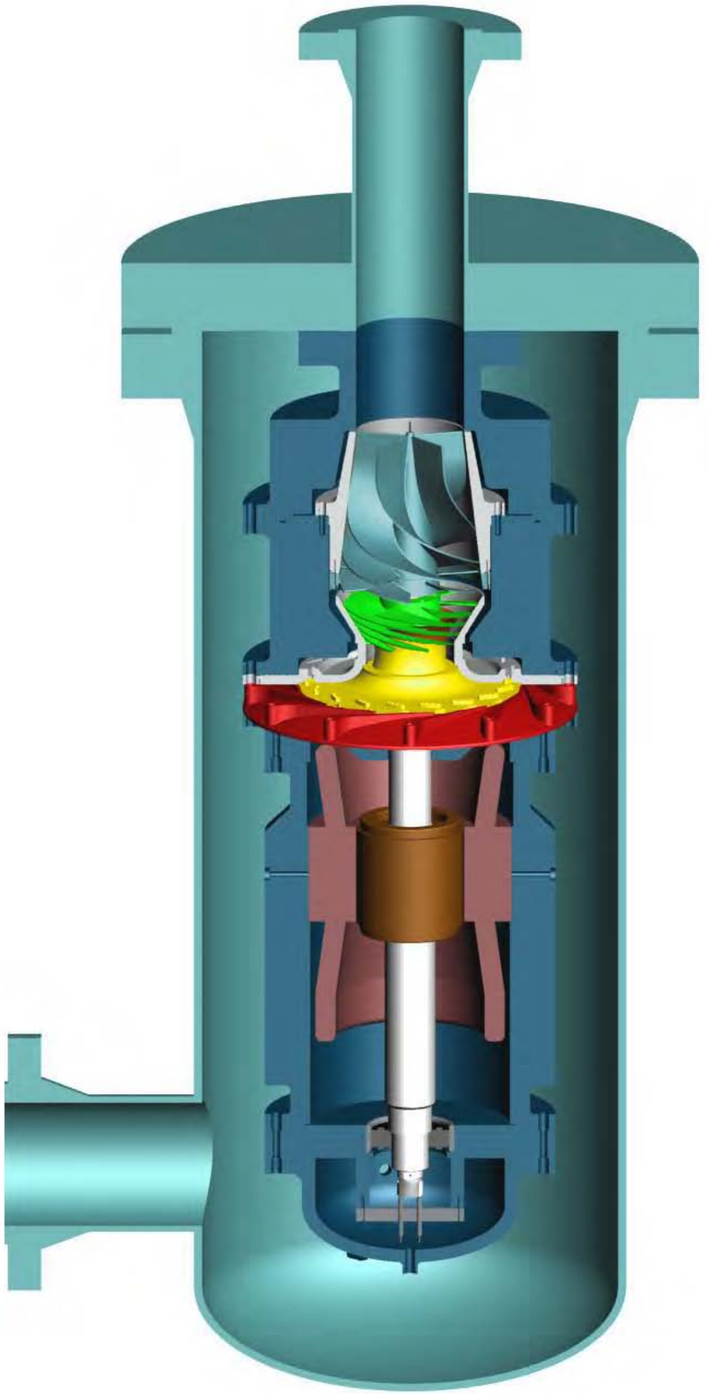
The theoretical maximum differential specific enthalpy dh is described by the following differential equation

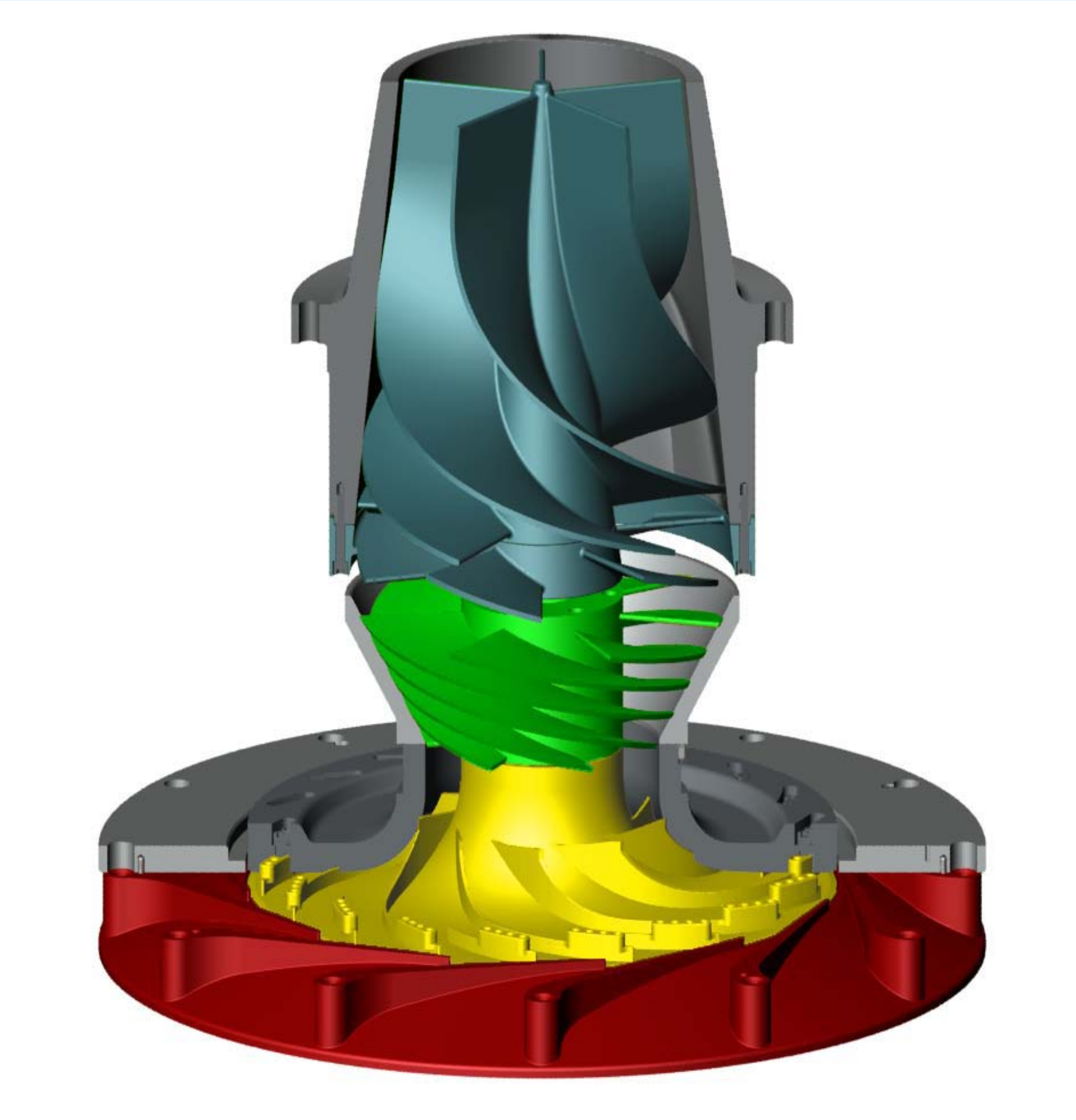
$$\boxed{\frac{\mathbf{dh}}{\mathbf{dp}} = \mathbf{v}[\mathbf{h}, \mathbf{p}]}$$

The maximum mechanical power output P is the product of the mass flow $\dot{m}$ and the specific enthalpy difference Δh between inlet and outlet

$$\boxed{\mathbf{P} = \dot{\mathbf{m}}\,\Delta\mathbf{h}}$$

Cross Section of the Two-Phase LNG Expander

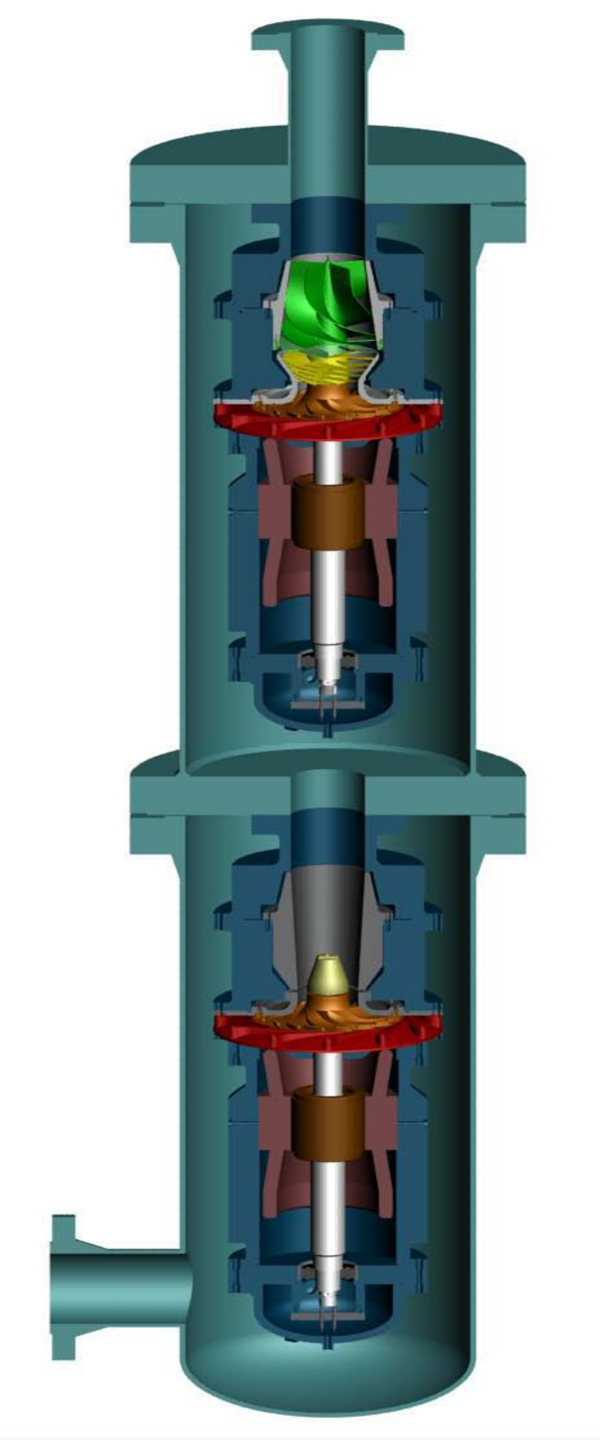




Hydraulic Assembly for Two-Phase Expansion applying Case C of the Euler Turbine Equation

Installation of the Very First Two-Phase LNG Expander in Poland 2001

Two-Phase
LNG Expanders
at the
Manufacturing
Plant



Combined
single and two-phase
LNG Expanders in
tandem configuration.
To optimize the power
generation, different
rotational speeds for
the higher density
single-phase and for
the lower density
two-phase LNG are
recommended.

Installation of the Tandem Configuration in Poland in 2009

Thank You

Vinod P. Patel
Hans E. Kimmel