Joule Thomson Valve

Oil & Gas

Refinery

The article is summarized a presentation, taken for World famous Oil/Gas majors and Korea leading EPCs engineers, when I worked as SEVERN GLOCON Korea regional manager, so that it may be helpful for the engineers.

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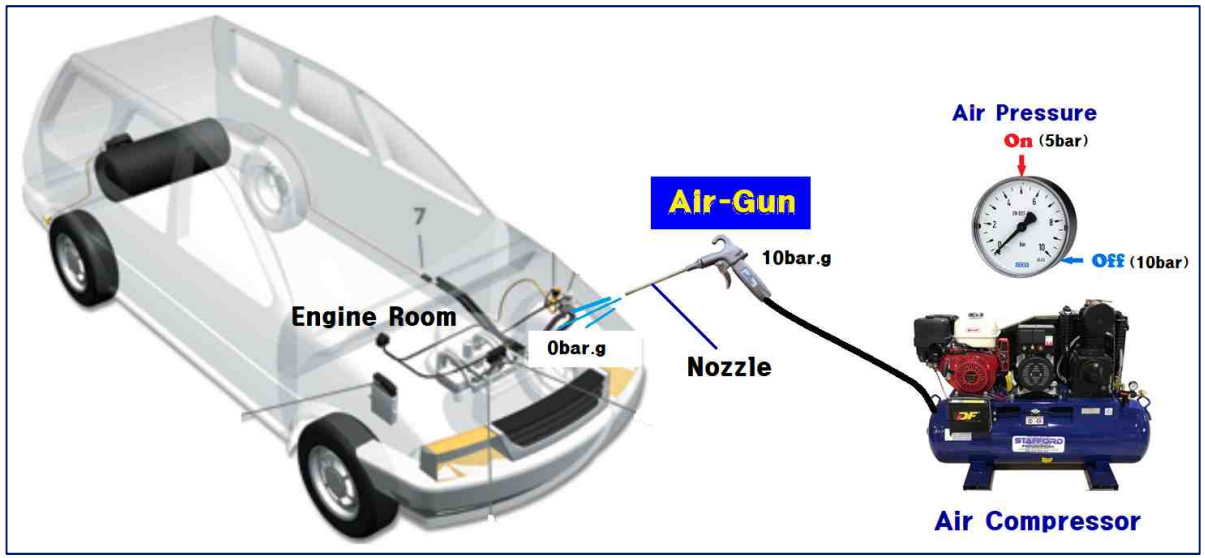
History

- Involves temperature change in a pressurized gas system by rapid expanding its volume or creating a sudden drop in pressure
- The effect discovered in 1852 by James Prescott Joule and William Thomson

We have to understand basically the 1st law of Thermodynamics and PH diagram from Physics (Thermodynamics) since Joule Thomson Valve is the valve adapting the nature of gas. Joule-Thomson effect is a kind of physics phenomenon, discovered in 1852 by Joule and Thomson, that the fluid gas temperature drops as the gas is expanded(pressure drop occurred) when it passes the narrow path like nozzle shape. The higher the pressure drop, the faster the flashing of liquid in the gas absorbs the surrounding heat and the temperature drops. All gases contain few amount of liquid depending on temperature and pressure. A representative example can be found at the car service center. Under a pressure drop of 10 bar, the compressed air is passed through a narrow nozzle of the air gun at a high speed, significantly lowering the air temperature at the nozzle outlet.

Engine Room Air Gun

The air contains 2wt% - 3.5wt% of moisture depending on the temperature and relative humidity. The air velocity (corresponding to a pressure drop) highly increases as it passes through the nozzle and the moisture evaporates quickly and the air temperature drops.



Joule-Thomson Effect?

$\Delta U = mCv\,\Delta T = Q + Emfd - \int pdV$

ΔU : Variation of internal energy in a system
(내부 에너지 변화 량)

m, : Mass of expanding gas(팽창 가스의 질량)

Cv : Specific thermal capacity at constant volume(정적 비열)

Q : Heat transfer(외부에서의 열 전달 양)

Emfd : Mechanical energy with friction loss(외부의 기계 에너지)

∫pdV : Work done for a system(시스템 에 제공한 일)

$\Delta U = mCv\,\Delta T = Q + Emfd - \int pdV$

Emfd≥0 in any process in an adiabatic process is known, hence the initial temperature of a system can be lowered (achieving ΔT<0) by forcing an expansion in a compressible fluid (dV>0)

Internal energy variation at the closed system, since no volume is constant and it's made with temperature variation, is same with the value of temperature variation multiplied by the inner gas mass multiplied by specific heat at constant volume:

$Cv = (\partial u/\partial T)\,v \rightarrow du = Cv\,\Delta T \rightarrow \Delta U = mCvdT$

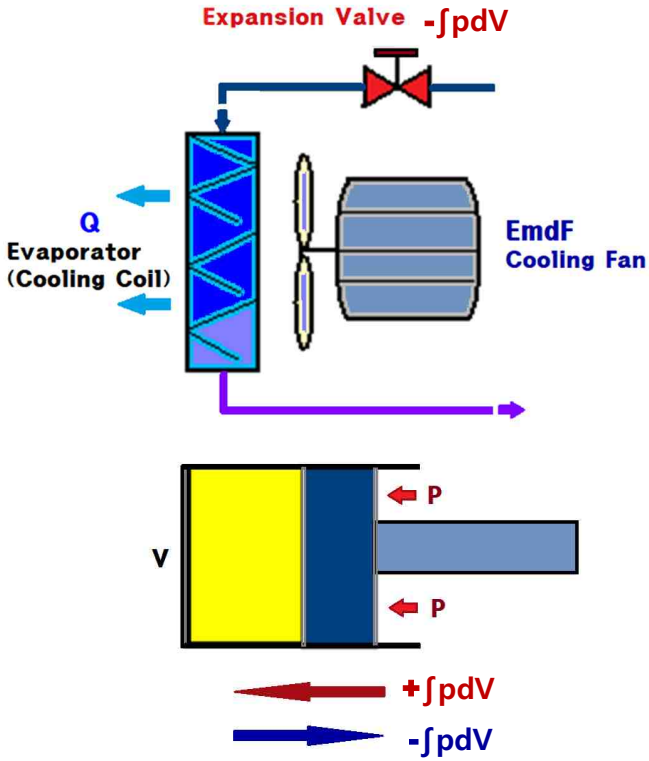
If we practically apply the formula to air-conditioner in the room with refrigeration system,

Q : The energy transferred from evaporation coil to the room inside

Emdf : The mechanical friction loss takes place due to rotation of cooling fan's impeller

$-\int pdV$: The work, done at expansion valve, means W= F(force) x L(length) = P(pressure) x A(Area) X L(Length) = P(pressure) x V(Volume).

The work shows the value of **$+\int pdV$** when the piston moves for compression (positive), but it moves for Expansion (negative) the value should be **$-\int pdV$**.



Joule Thomson Coefficient

- **Another common formula to describe Joule-Thomson Effect is Joule-Thomson Coefficient**

$$\mu JT = (\partial T/ \partial P)H$$

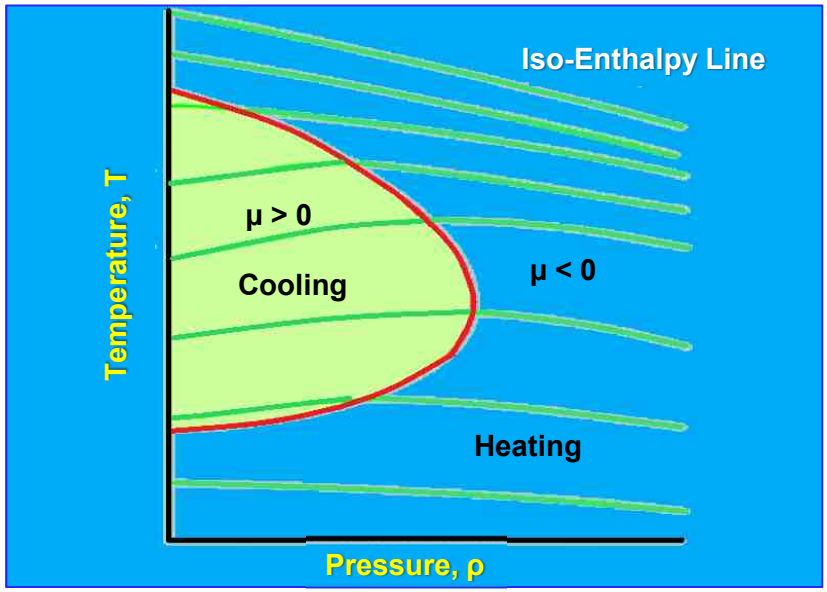
- **In case fluid expansion occurs ($\partial P<0$) when $\mu JT >0$, the final temperature is lower than the initial ($\partial T<0$)**
- **$\mu JT= 0$ for ideal gas**
- **The Coefficient is generally positive at low T & P**

- Mechanical energy in an adiabatic process is always bigger than 0 and the gas volume is expanded ($dV>0$), then the initial temperature drops($\Delta T<0$).
- Joule Thomson effect can be described to another formula of Joule Thomson Coefficient.
- The fluid enthalpy moved to other system remains unchanged in accordance with the 1st law of Thermodynamics although the fluid is moved from a certain system to other system. Hence the process is Iso-enthalpy process. Therefore, the coefficient is decided by the factor of Temperature and Pressure in Iso-enthalpy process. It is formulated that the pressure drops, consequently the temperature drops.
- For ideal gas, the pressure is in inverse proportion to the volume if the temperature is constant according to Boyle's law. It means the formula is brought as below

$$P1V1 = P2V2, \quad PV = Constant$$

We say inversely, the temperature is constant without change although the pressure or volume is changed.
Accordingly, **$\mu JT = 0$ is come from $\partial T = 0$ at $\mu JT = (\partial T/\partial P)_H$**

Inversion Line



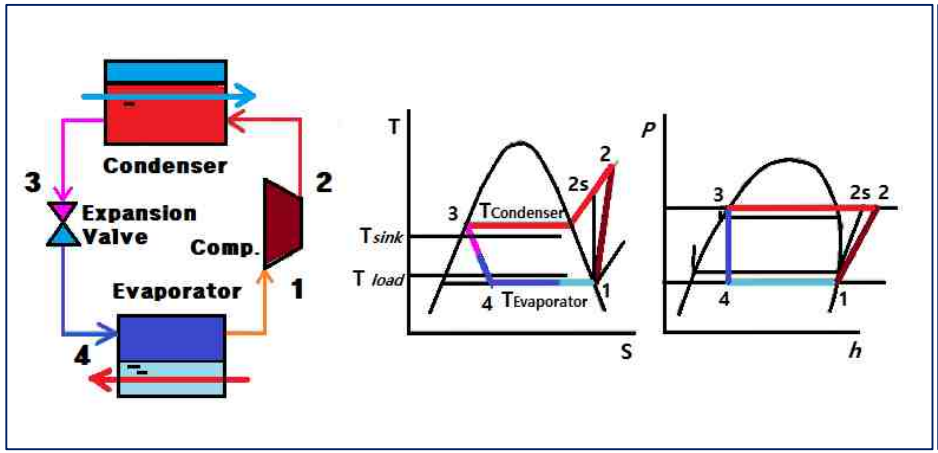
Maximum Inversion Temperature for Various Gas

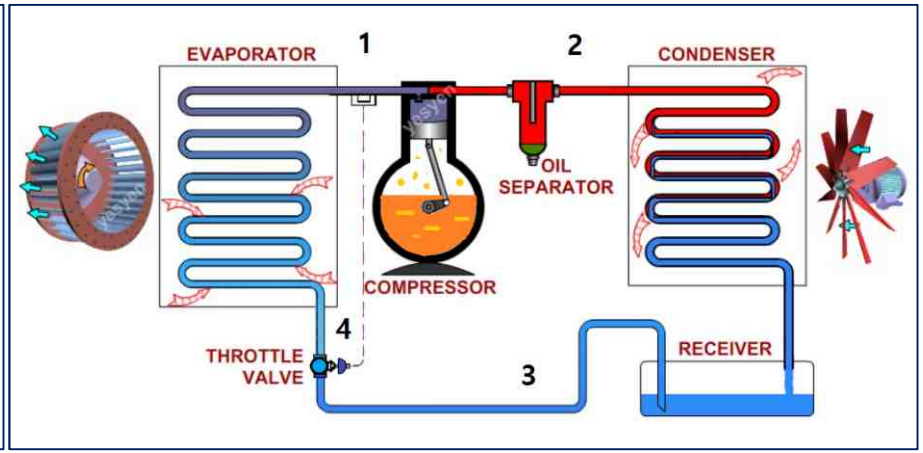
Gas	Max. Inversion Temp.(K)
Helium(He)	45
Hydrogen(H2)	205
Neon	250
Nitrogen(N2)	621
Oxygen(O2)	761
Air	603
Carbon dioxide	939
Methane	1,500
Ammonia	1,994

- There is the point that the curve slope is inversed as we can see the above picture.
  We call it “Inversion point”, and the temperature at the point is called as “Inversion temperature”. The points are connected in turn, then “Inversion Line” is made.
  Finally, the cooling effect, that the temperature drops by drop of pressure, takes place in the left area of Inversion line.
  The cooling effect does not take place in the territory above “Inversion temperature” since the territory with positive(+) Joule Thomson Coefficient does not exist. It means the cooling effect can take place at the proper low temperature and pressure.

Applications

Simplified Schematic for Refrigeration System





Joule Thomson effect takes place in 3-4 process of an adiabatic expansion process in the refrigeration system.
Accordingly, Joule Thomson valve is applied to generate the cooling effect by throttling in the process.

Here,

1-2 process : Adiabatic compression process in Iso-entropy process at the compressor

2-3 process : Isothermal(constant pressure) condensing process at the condenser

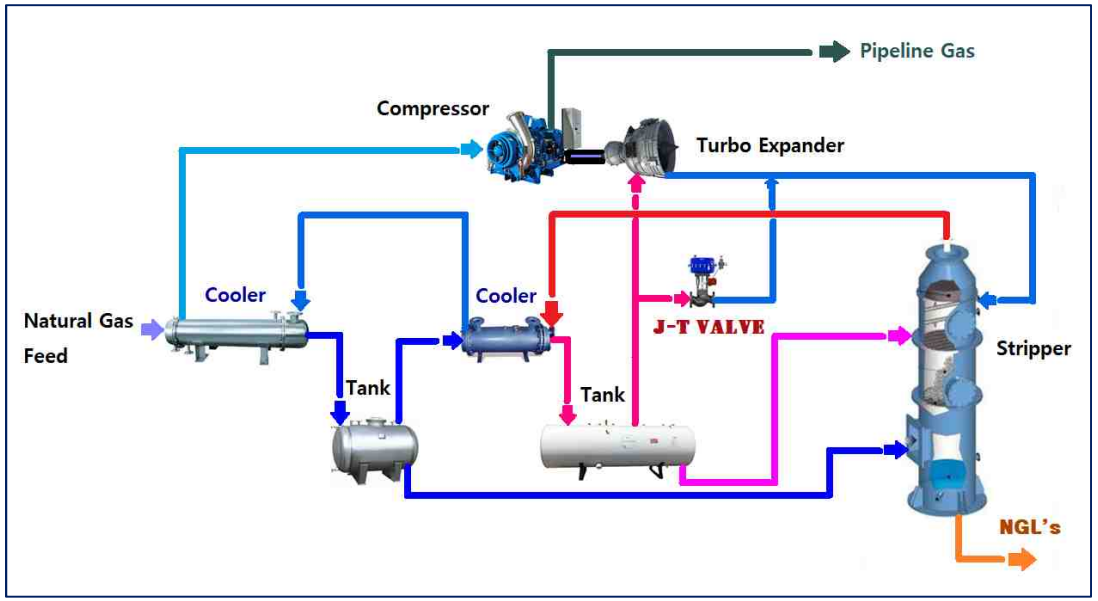
3-4 process : Iso-enthalpy expansion process at the expansion valve

4-1 process : Isothermal(constant volume) evaporation process at the evaporator

Improved System for Turbo Expander

Expansion brings 2 positive effects through expansion by 2 phase turbine

- Power production
- Temp. is lowered with same pressure drop due to less heat produced by friction

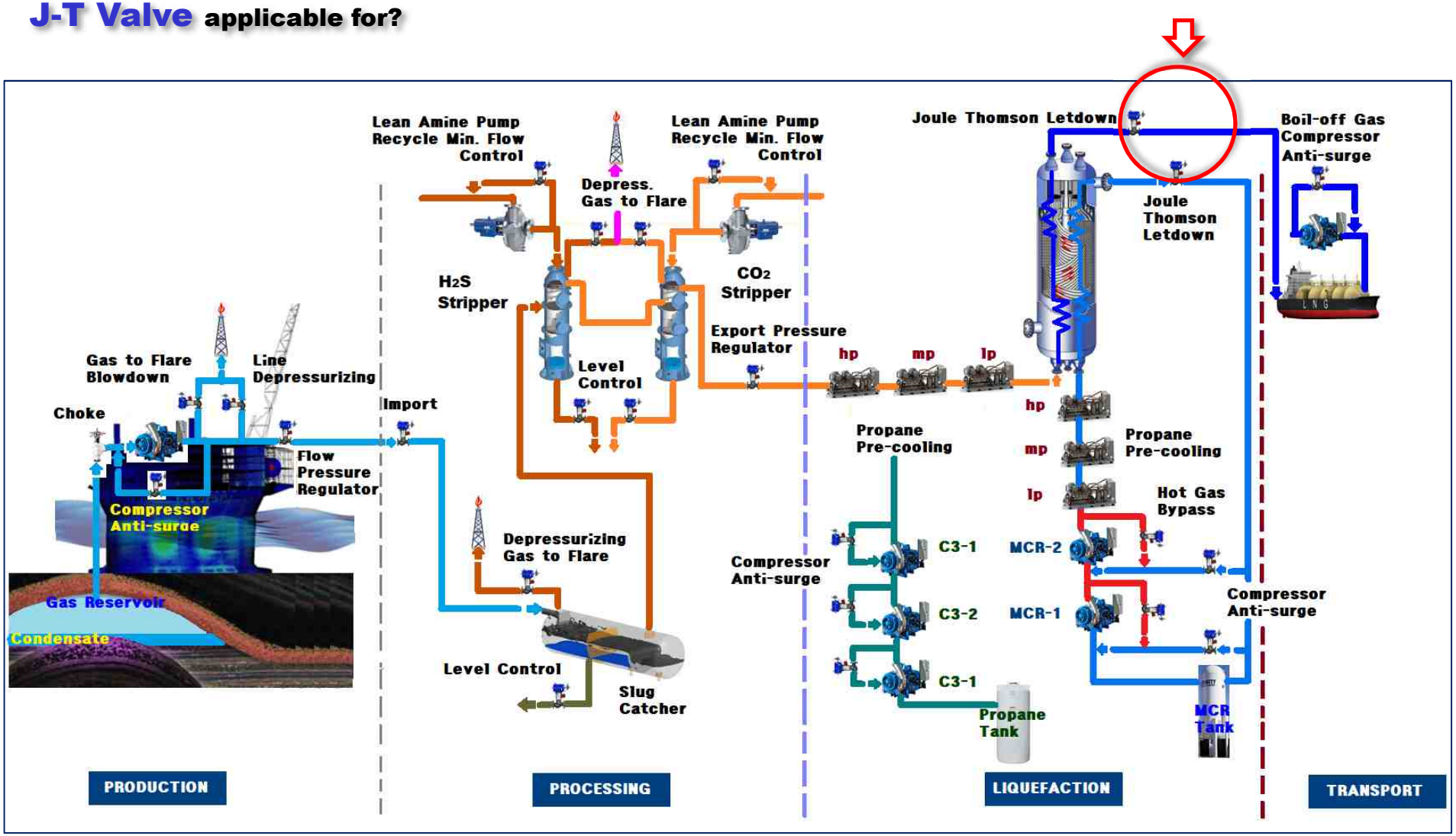


Joule Thompson Valve operates for

- Start up & shut down of the expander
- Turbo expander trip
- Flow rate exceeds the turbine capacity
- Propane refrigeration
- Ethylene/ Propylene/ LNG production
- Air separation
- Oxygen plant
- Gas liquefaction
- Mixed hydrocarbon refrigeration
- Ammonia plant
- Gas cleaning
- High density polyethylene production
- Urea plants

2 positive effects can be made by expanding 2 phase fluid through Turbo expander.
It brings to drive the compressor and cool the gas down.
The role of J-T valve is to bypass the gas at start-up and shutdown, trip or excessive flow rate of Turbo Expander. In this case, 50% over capacity margin of flow rate at Turbo Expander's normal operation should be taken into account for valve sizing.

J-T Valve applicable for?



J-T valve is mostly applied to the system of Cryogenic service and makes the fluid reached the cryogenic temperature.
The temperature of fluid at LNG liquefaction process plant shall be cooled down up to the desired temperature subject to the employment of J-T valve.

Typical Requirements

- Special material selection - Cryogenic temperature
- Short stroke speed (to open) – Protect the expander
- Tight shut off – Avoid leakage
- Valve – Same capacity as expander to guarantee seamless transition between expander and valve operation

The typical requirements of J-T valve are,

1. The material is normally St. Steel(304, 316), Monel, and Aluminum for cryogenic service.
2. The valve quick opening is required to prevent the expander trip.
3. The icing occurs at valve stem & bonnet area and it may cause malfunction of positioner as well as the poor valve open/close in case LNG (cryogenic temperature) is leaked.
4. J-T valve is selected with the capacity same with expander's for smooth operation.

Problems

- Noise
- Vibration
- Clogging due to hydrates formation
- Leakage through the packing due at cryogenic temperature
- Thermal binding

Typical Process Condition

- Inlet pressure : 48.3 – 103.4 bar
- Outlet pressure : 13.8 – 48.3 bar
- Cryogenic service : Temperature down to -160℃

The frequent problems are Noise, Vibration caused by the kinetic energy with high pressure drop, and the trim path will be clogged due to hydration and icing if the temperature drops below the temperature of the gas hydrate line. The leak problem is critical with the selection of packing material at cryogenic temperature.
The temperature can be lowered to the desired level by J-T valve.

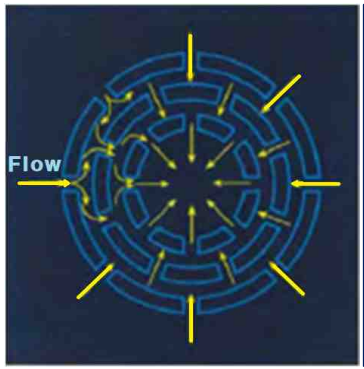
Key Factors for valve selection

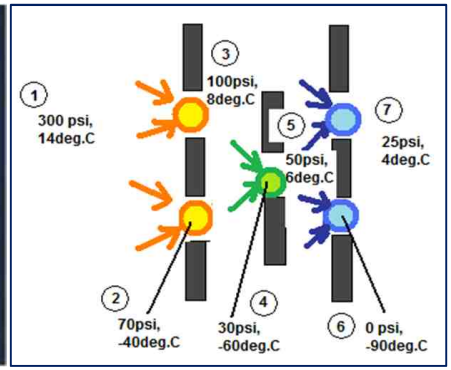
The customized trim design is required based on specific requirements. Manufacturer shall provide a complete solution to :

- Noise
- Vibration
- Leakage
- Clogging

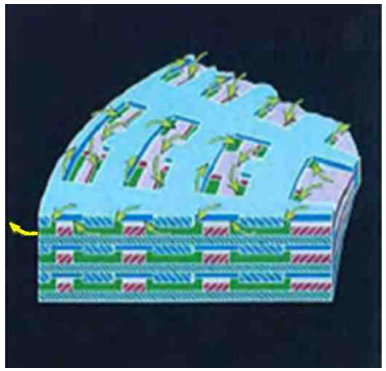
The big pressure drop normally takes place through the valve since the temperature drops enough to cool down. The temperature shall be lowered to -160℃ in case of LNG process.
Severn Glocon selects and recommends the valve to prevent the above mentioned problems in advance.

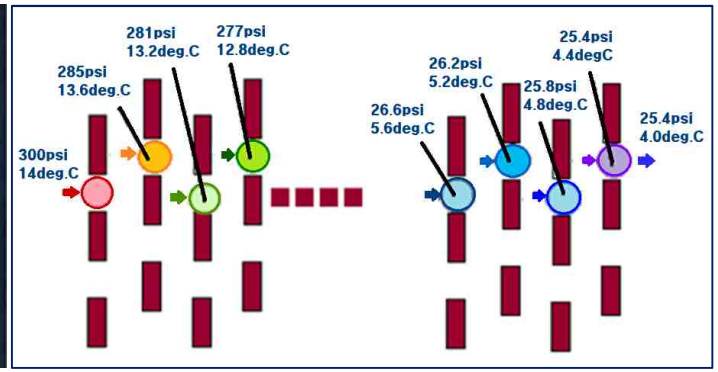
Multi-stage, Multi-path Design





4 stages Cage Trim

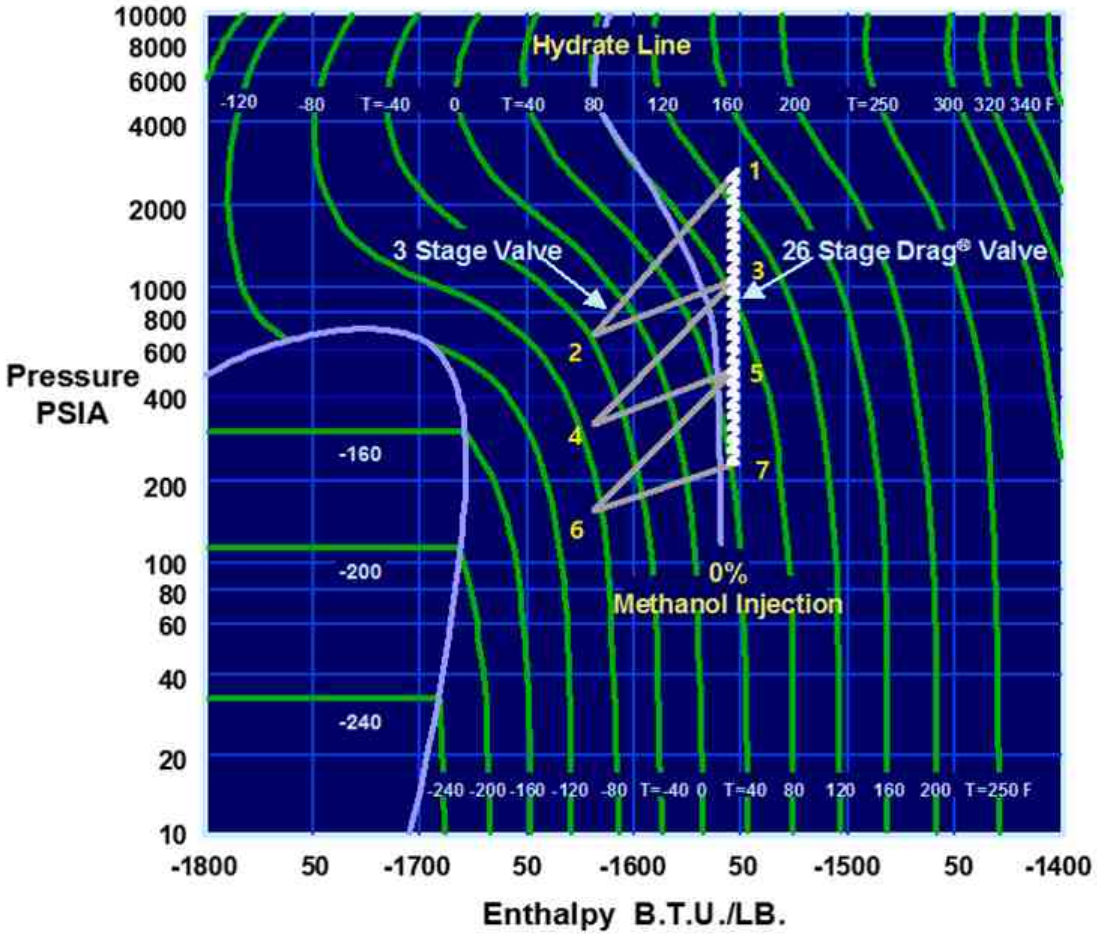


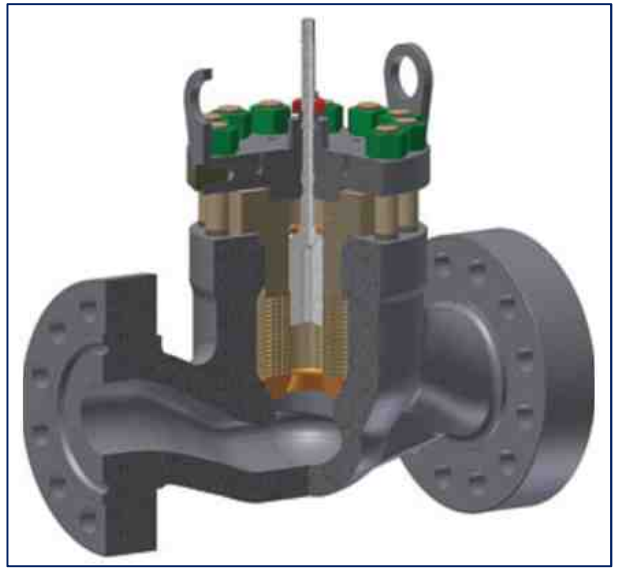


26 stages MLT Trim

Severn Glocon's 26 stages MLT trim(Multi-Labyrinth Trim) design with Multi-stage/Multi-path is recommendable to lower the pressure gradually so that the hydrate may not form, and to control the fluid velocity and to absorb the kinetic energy at each stage, and so the noise and vibration may not occur.

Pressure-Enthalpy Diagram (Methane)





Multi-stage/Multi-path Trim Control Valve

The heat energy shall be converted to the kinetic energy for the fluid to move from the system to other system through narrow path, and at this time the fluid's enthalpy and temperature drops by Joule Thomson effect. Then the enthalpy of the fluid is recovered to the initial state (Iso-enthalpy) when the fluid reaches into other system in accordance with the 1st law of Thermodynamics. The fluid temperature drops below the hydrate line due to high pressure drop at each stage in case the temperature is lowered by the valve with 3 stage trim, and at this time the hydrate forms and the ice is made at freezing temperature and the phenomenon clogging the trim path occurs(Clogging).