APPLICATION NOTE

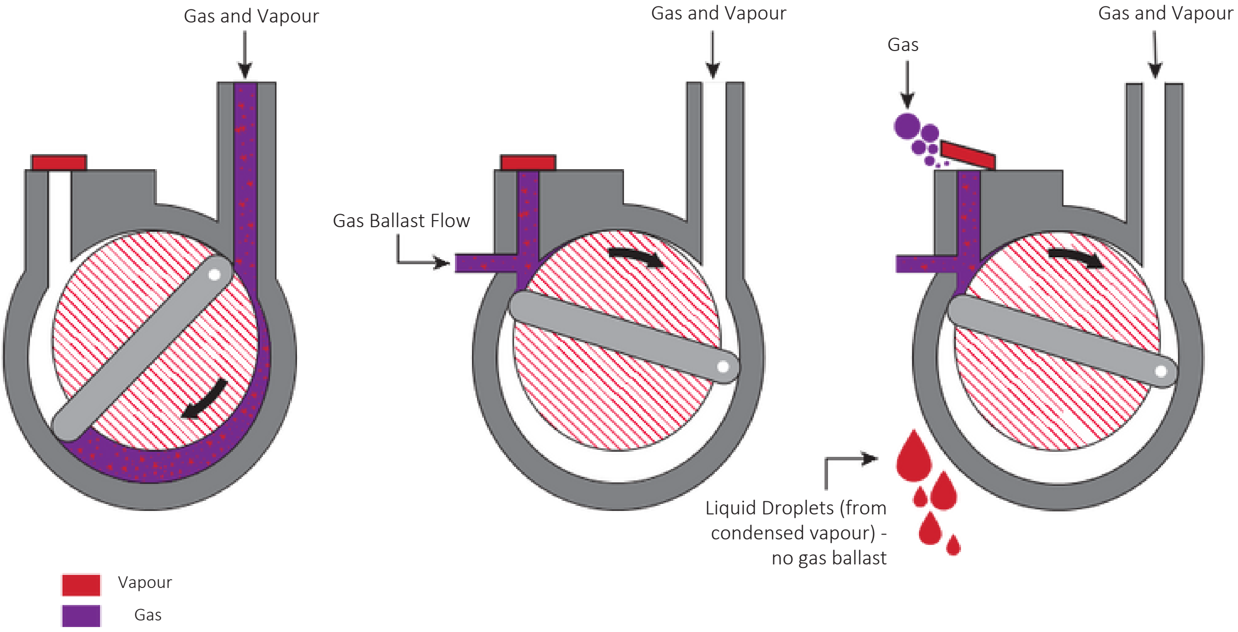
THE PRINCIPLE AND APPLICATION OF GAS BALLAST

edwardsvacuum.com

Outline

Gas ballast is a constructional feature widely applied in many primary vacuum pumps for the pumping of vapours. Wolfgang Gaede invented the gas-ballast principle in 1935 and was originally focussed on primary oil sealed pumps. Gas ballast is useful in reducing the extent of vapour contamination in the oil (and/or other parts) thus extending oil life and at a more fundamental level permitting the pump to operate on vapour duty at nearly full specifications. Put simply, depending on the percentage make-up of vapour in the pumped load, then without gas ballast the pump can ‘stagnate’.

A typical physical representation of the gas ballast configuration is shown below



The basic principle of ballast is that atmospheric air (or CDA or inert gas) is admitted into a pump during the (late) compression stages (as above). This increases the percentage of non-condensable gas such that the partial pressure of the vapour being pumped is below its saturated vapour pressure when the exhaust valve opens (typically at a pressure of 1.05 to 1.2 bara). This means that the vapour is discharged from the pump without liquefaction.

The work performed from ballasting tends to increase the operating temperature which again helps with vapour handling (as shown in the analysis below).

N.B. when we talk about vapour pressure we usually mean the saturated vapour pressure

Theory

The maximum vapour handling capacity (MVHC) of a pump is the maximum amount of vapour that can be pumped without condensation in the pump (as discussed above); the vapour being compressed such that it just avoids saturation at the point of exhaust. The Maximum Water Vapour Handling Capacity (MWVHC) refers to the specific case of water vapour handling and this is a measure quoted for pump performance and is used a relative measure.

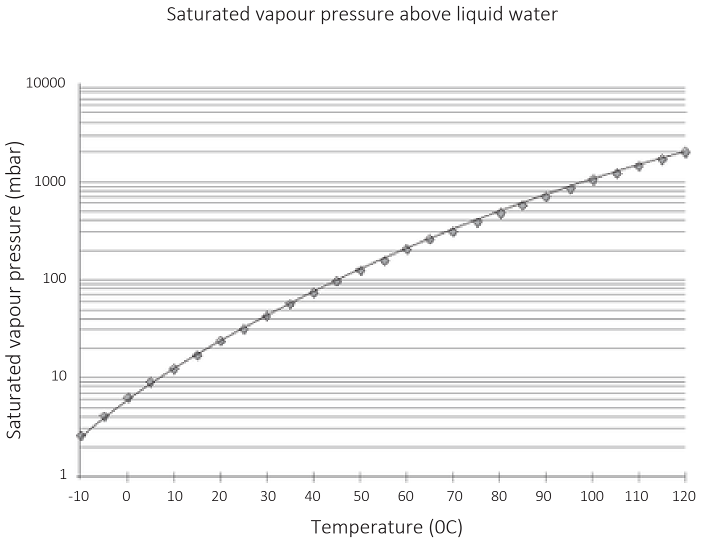
Thermodynamic considerations (see references) show that the maximum mass flow rate of vapour, w, without condensation occurring in the pump is

$w = Q_b P_{sv} M\,[(P_e - P_{sv}).R_o T_b]^{-1}$..eq.1

where:
Q_b is the gas ballast flow rate (usually atmospheric air)
T_b is the ballast gas temperature (N.B. the effect of ballast gas humidity is small and usually ignored)
M is the molar mass of the vapour
R_o is the gas constant
P_e is the pressure at the exhaust (the pressure needed to open an exhaust valve)
P_{sv} is the saturation vapour pressure (SVP) corresponding to the coldest point in the pump (often the exhaust point)

Example

Calculate the MWVHC of an RV5 OSRV pump operating at an estimated (minimum) temperature of 65°C. At this temperature the SVP of water is 250.1 mbar = 25,010 Pa



The RV5 has two gas ballast operating settings: GB1 is 5 slm atmospheric gas flow and GB2 is ~ 16 slm atmospheric gas flow @ 20°C

For GB1 $Q_b = 5$ slm = 9.06 Pa.m^3/s

T_b = 20°C =293K

P_e = 1,200 mbar (exhaust opening pressure) = 120,000 Pa

P_{sv} = 250.1 mbar (saturated vapour pressure at the lowest internal temperature) = 25,010 Pa

R_o = 8.314 J.mole^{-1}K^{-1}

M = 0.018 kg/mole

hence w = 1.76×10^{-5} kg/s = 0.063 kg/h = 63 g/h

The figures quoted in the catalogue are 0.06 kg/h and 0.22 kg/h for GB1 and GB2 respectively.

An alternative working formula (from Lafferty) is

$w = 0.75\, V\, p_{sv}/(p_e - p_{sv})$ in kg/h.......................................eq.2

where p_{sv} and p_e are in mbar and V is the gas ballast volumetric flow in m^3/h

For the above example RV5 and case of GB1: p_{sv} = 250.1 mbar, p_e = 1200 mbar
For a GB1 (atmospheric) flow of 5 slm: V = 0.322 m^3/h @ 20°C
hence w = 0.75*0.322*250/(1200-250) = 0.064 kg/h = 64 g/h

this is in reasonable agreement with the value of 63 g/h calculated using eq.1 and 60 g/h quoted in the catalogue.

Note that the speed of the pump is not a determining factor to the MWVHC. However it does influence the degree of degradation of the inlet pressure and the operating pressure at a given vapour flow rate.

The operating temperature of the pump, the exhaust valve opening pressure and the gas ballast flow rate are the major factors in maximising the MWVHC.

The gas ballast flow rate will be determined by a combination of the considerations of the vapour capacity required and the degrading effect the ballast flow has on the inlet pressure. The positioning of the gas ballast introduction point to the pumping medium (e.g. ensuring the correct point in the wraps of a scroll pump) is crucial: it has to be close enough to the pump inlet to ensure no condensation during the progressive compression but at a point where the ultimate pressure during ballast flow is not overly corrupted.

The water vapour tolerance of a pump P_t is the highest intake pressure which a gas ballast pump, under normal ambient conditions (20°C, 1013.25 mbar) can pump and exhaust water vapour in continuous operation (PNEUROP 6602, DIN 28426 and BS).

As discussed earlier, if a pump can tolerate condensation the actual tolerance will be higher than this figure.

By definition, $P_t = (R_o T_b / M) . w/S$............................eq.3

where S is the pumping speed at the maximum throughput of water. The same characteristic speed curve for water as for air is assumed. For the example of an RV5 we calculate for GB2 (applying values in SI units)

P_t = (8.3*293/0.018)*(0.23/3,600)*(3,600/5.1) = 6050 Pa = 61 mbar

The quoted figure in the catalogue is 50 mbar
P_t varies inversely with pumping speed hence for the RV8, theoretically
P_t is 60.5 5.1/8.5 = 36 mbar c.f. 38 mbar quoted.

No gas ballast: permissible vapour partial pressure/permanent gas ratio

In the case of no gas ballast being used the permissible ratio R_p of vapour partial pressure/permanent gas partial pressure for no condensation to occur is

$R_p = P_v/P_{permanent} = [(P_e/P_{sv}) - 1]^{-1}$................................eq.4

for the above RV5 example

R_p = 1/[(120,000/25,000) – 1] = 0.263 = 26.3%

It is important to note that these values reflect the pump’s ability with vapour, not the consequences of condensation.
The nXDS/XDS scroll pumps can tolerate some condensation within the pump mechanism, largely because of the choice of tip seal material and the fact that the bearings are shielded from the process vapours.

Comments

- MWVHC is independent of pump speed/displacement: The operating temperature of the pump, the exhaust valve opening pressure and the gas ballast flow rate are the major factors in maximising the MWVHC.

- Gas ballast principle applies to OSRV pumps and can be applied to scroll, multi-stage roots and other pump mechanisms pumps due to their specific pumping mechanisms (and exhaust configuration).

- Gas ballasting can also be used ‘retrospectively’ to purge condensed and dissolved vapours from the oil/other materials of the pump’s mechanism.

- Generally a pump should be operated with ballast and allowed to reach full temperature (~1 to 2 hours) before any condensable vapours are introduced. Similarly after vapours have been processed the pump should be operated on GB for another 30-60 mins before turning the pump off (this prevents condensation in a non-running, cooling pump).

- Generally ballast flow is ~ 5% free air displacement for a two-stage OSRV and 10% for a single stage OSRV. RV5 GB1 = 5 slm hence ballast is ~ 0.32m^3/h and for GB2 = 18 slm speed is ~1.2 m^3/h (at standard atmospheric pressure).

- Point of GB inlet: ballast should be introduced where it effects the ultimate least but avoids condensation occurring in compression.

- When using GB an OSRV pump may need an oil return kit as there will be carry-over oil loss.

- The gas ballast port can be used as a convenient point to introduce dilution; this may be to keep materials processed out of the flammable zone, below toxicity levels and also mitigate any corrosive effects. Note though that the level of dilution needed to keep out of the flammable range and below toxicity etc. maybe more than is allowable through the GB setting.

- The effect of ballast humidity is small and is neglected though strictly mostly for the case of pumps running at a temperature > 70°C.

References

- *Chambers A, Modern Vacuum Physics, pp122-126 (2005)*
- *Gaede W, Gas Ballast Pumpen, Z Naturforsch, 2a, pp233-238 (1947)*
- *Lafferty J, Foundations of Vacuum Science and Technology, pp 144-147 (1998)*
- *Power B D and Kenna R A, Vapour Pumping Characteristics, Vacuum, Vol. V, pp35-58 (1957)*
- *Roth A, Vacuum Technology, pp207-209 (1976)*
- *Wutz M, Adam H and Walcher W, Theory and Practice of Vacuum Technology, pp158-162 (1989)*

Publication Number: 3601 2094 01

Edwards Ltd, registered in England and Wales
No. 6124750, registered office: Innovation Drive,
Burgess Hill, West Sussex, RH15 9TW, UK.