Vacuum requirements for steel degassing

Steel degassing requires equipment with large pumping capacity and the ability to deal with large amounts of dust. Compared to steam ejector systems, dry mechanical vacuum systems offer savings in space, speed, flexibility and running and maintenance costs.

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Investment in steel vacuum degassing processes, both in new plant and upgrades of existing plant, is continuing as steel companies see the opportunity to increase the value of their products by improving quality and supplying more special steels.

For reasons of economy these processes are usually conducted on a large scale and consequently very large vacuum pumping capacities are usually required. The processes are also potentially very dirty, with large amounts of metallic fines and oxide dust being generated. Historically much vacuum degassing has been done using multiple steam ejector stages backed by hogging steam ejectors or large water ring pumps. These systems traditionally require a lot of maintenance and consume extremely large amounts of expensive steam, generated by substantial steam-raising plant.

Historically oil-sealed vacuum pumps have never been considered robust enough to offer a less expensive solution, but as pressure increases on steel companies to reduce both energy expenditure and plant maintenance they are now looking to dry mechanical vacuum pumping systems, with much better dust handling capabilities, to provide significant savings.

Compared to steam ejector systems, dry mechanical vacuum systems offer clear savings in installation space, running and maintenance costs, and also offer increased speed, flexibility, and overall productivity to steel degassing operations. Large Roots vacuum booster pumps designed for high dust tolerance are the major component of mechanical vacuum degassing systems.

Steel degassing processes

Steel degassing is an essential process in secondary steelmaking. Its value is in its rapid and effective removal of dissolved contaminant gases from primary steel (principally hydrogen and carbon monoxide) and the reduction in dissolved carbon levels, resulting in higher quality and higher value steel product with more widespread applicability. The two main processes are vacuum degassing (VD) and vacuum oxygen decarburisation (VOD).

Vacuum degassing The basic VD process usually lasts 15–20 minutes and is conducted at pressures in the region of 0.67mbar (0.5torr). Under these conditions much of the dissolved hydrogen and carbon monoxide gases in the liquid metal desorb into the atmosphere above the steel and are evacuated. This process can also assist with the removal of sulphur and lighter, more volatile metal elements such as Pb, Sn, As, Sb and Bi. Residual hydrogen levels can typically be as low as one ppm and soft purging with argon at the end of the process can also reduce residual oxygen levels to below 15ppm.

Gas flows of many tens of kg/h air-equivalent must be handled at 0.67mbar, which requires pumping speed capacities of tens of thousands of m^3/h as a minimum, and demands the use of very large, multi-stage pump sets based on Roots vacuum boosters.

Vacuum oxygen decarburisation The VOD process is used typically to reduce the carbon content of high chromium stainless steels while avoiding significant collateral losses of chromium by oxidation. It uses the injection of pure oxygen into the molten steel to 'burn out' dissolved carbon by high temperature conversion to CO and CO_2 which are then evacuated.

To avoid undue losses of chromium the process is usually conducted at pressures of around 80-200mbar (60–150torr). Extremely large amounts of dust and fines can be generated by this process which may, or may not, be captured by large filtration systems. At these pressures the pumping speed capacities required are much less than for VD, however, large Roots vacuum boosters are still needed.

Other processes

Similar vacuum processes requiring high capacity pumping are vacuum arc degassing (VAD) and vacuum induction degassing (VID), which use alternative forms of heating to achieve similar objectives.

Process type	VD & VOD or VD only
Heat mass (capacity)	Tonnes of liquid metal
Furnace volume	2–3m^3 per tonne
Furnace air leakage	Up to 10kg/h (air@20°C)
Initial pump down time to VD	5–7mins
VD process pressure	0.67mbar (0.5torr)
VD suction capacity	1–2 kg/h/t (air@20°C) 1,250–2,500m^3/h/t
VD line diameter	800–1,000mm
VD gas dust load to pump system	Very low
VD gas temperature to pump system	Should be <= 60°C
VOD process pressure	80–200mbar (60-150torr)
VOD suction capacity	Variable
VOD line diameter	800–1000mm
VOD gas dust load to pump system	Can be high if filtration is poor
VOD gas temperature to pump system	Should be <= 60°C

● **Table 1** ***Pumping performance requirements***

Pumping performance requirements
Basic performance parameters and requirements in a typical steel degassing pump system are shown in *Table 1*.

To meet these high-speed vacuum pumping requirements, the system should use an adequate number of large high vacuum (HV) Roots booster pumps, which are staged correctly to achieve sufficient pumping speed, while maintaining a satisfactory pressure ratio across each stage. These should be backed by primary pumps of sufficient capacity. The selection of primary pumps for backing stages depends on the type and size of the process, the available site facilities and any customer preferences as follows:

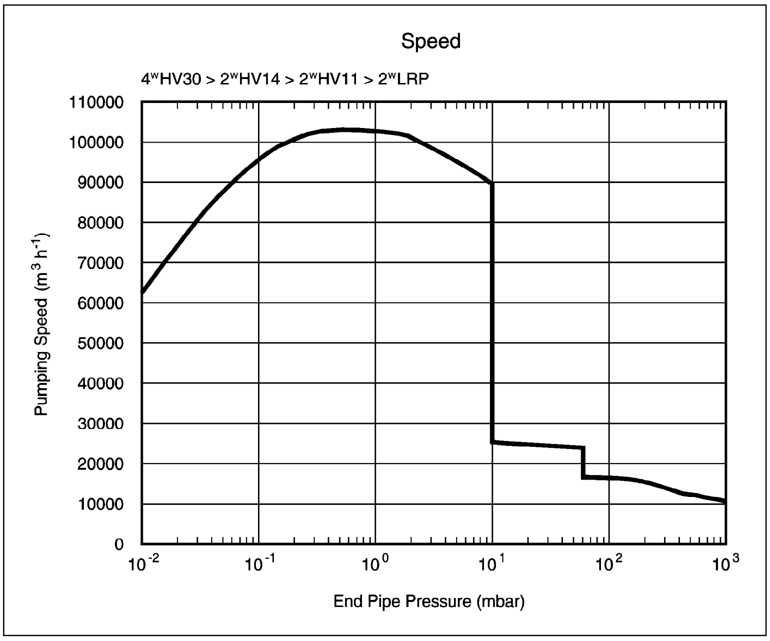
Backing pump options For VD processes, the general requirement for backing is to provide a reliable and adequate pumping speed at pressures in the region of 10-50mbar (7.5–37.5torr). For VOD processes this means provision of reliable, high pumping speeds working in the region of 200-400mbar (150–300torr), and tolerance to reasonable levels of dust and contaminants.

Dry pump sets Dry pump sets, such as medium-sized Roots boosters and dry claw primary pumps, provide good backing speed to HV booster stages for VD operation (ie, in the 10–50mbar region) and will also have excellent abilities to handle abrasive dusts, even in the high amounts which can arise from the VOD process. Much positive operating experience has been achieved with claw pumps even with severe dust loads on steel degassing plants, demonstrating simplicity of operation with high reliability. However, for larger plants a larger set of dry backing pumps is clearly needed, and economics may dictate that other backing options may need to be considered.

Liquid ring pumps (LRPs) Large LRPs (or WRPs – water ring pumps) are a very economic and reliable way to generate fast roughing and high-capacity backing for large sets of HV boosters. They are well accepted in the steel industry as simple, reliable pumps for hogging and higher pressure processes (eg, VOD), and have been a standard alternative for steam ejectors in these duties for many years. They are inherently quite tolerant of process dust and dirt since these are largely absorbed and flushed out with the seal water.

LRPs have a vaned rotor eccentrically mounted (slightly high) in a partially flooded horizontal cylindrical stator, driven by a suitably large motor. On start-up, the centrifugal action of the rotor rapidly establishes a circular liquid ring around the shell of the stator, with more gas space on the low side than on the high side. Vents in the lower side plates allow gas to be drawn in by the circulating rotor, which is then compressed on the high side by the liquid ring and vented out via non-return flapper valves in the upper side plates. The exiting gas is separated from entrained seal liquid, which can then be recycled.

However, there are two major drawbacks associated with the use of water-sealed LRPs for steel degassing:



● **Figure 1** ***Typical pressure-time (speed) curve***

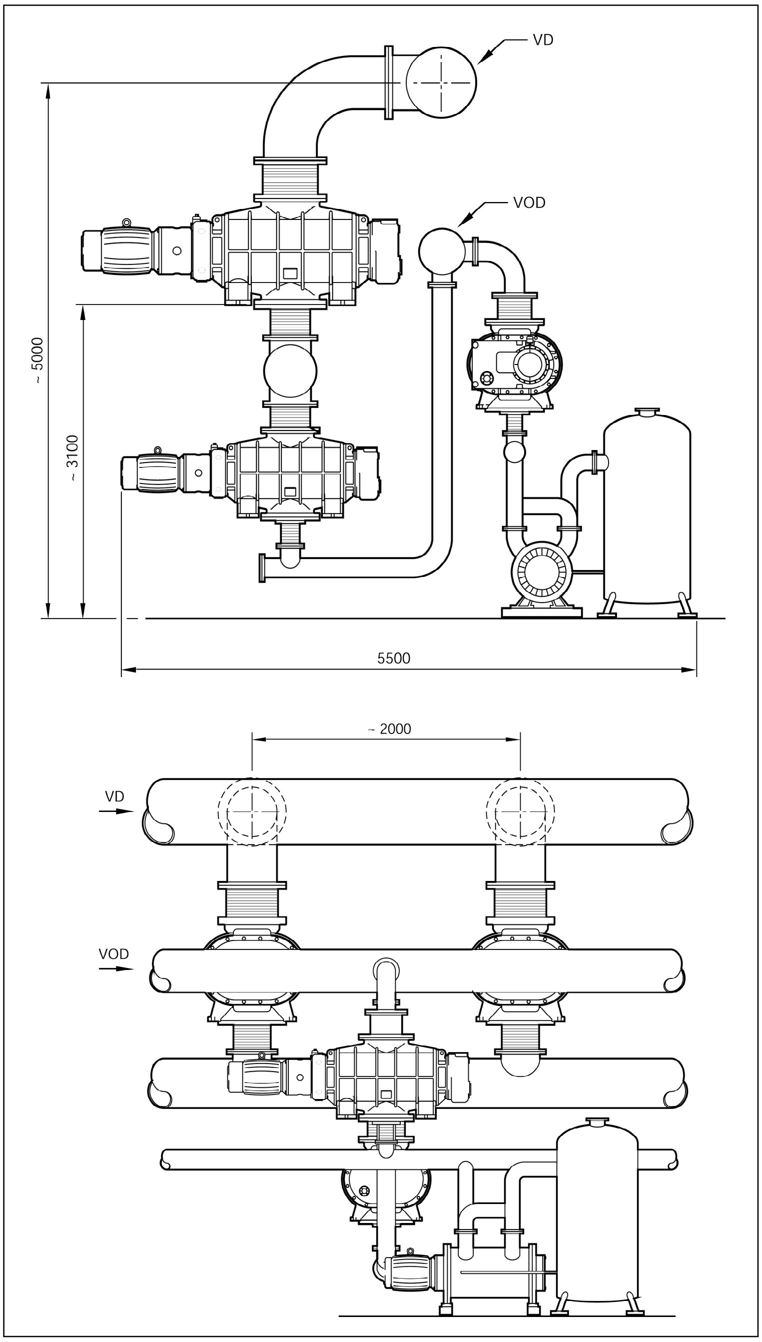
The seal water consumption is large A typical 4,200m^3/h LRP may consume up to 10m^3/h water in standard operation (50% recycled) or 20m^3/h water in 'once-through' mode (ie, no water recycling), and this water will exit straight to the waste water treatment plant. The incoming seal water must be clean but the effluent can be highly contaminated by steel degassing processes – potentially a significant environmental consequence. The manufacturer may recommend once-through mode for VOD processes to minimise abrasion and wear inside the pump.

The seal water temperature limits the ultimate pressure achievable Seal water temperature is critical to LRP performance particularly for VD backing where the LRP must achieve a good ultimate vacuum to avoid stressing the stage three HV boosters, causing excessive pressure ratio. LRP manufacturers' specifications are usually based on 15°C seal water temperature, which can be quite unrealistic, and care must be taken to establish the expected performance with the actual water temperature limits for the application (consult manufacturer's charts or ask specifically). As the seal water temperature increases so does its vapour pressure, which impairs the LRP's vacuum pumping speed and also begins to cause cavitation (vapour bubble 'explosions') within the LRP as the inlet pressure drops towards ultimate.

Although many manufacturers incorporate anti-cavitation devices, the net result is significant loss of pumping speed, cavitation noise/vibration, and especially a poorer ultimate pressure. Where this would have a critical and unacceptable impact on VD performance this must be dealt with by one or more of the following:

- Use once-through water (a likely requirement anyway)
- Chill the seal water (high plant and energy cost – may not be economic)
- Add an air ejector stage in front of the LRP (can be fed from the exhaust – but not liked by some operators)
- Add a small Roots booster stage in front of the LRP (adds cost and complexity)

Large dry exhausters Big roughing capacity at proportionately lower cost than with other dry pumps can also be provided using large dry exhausters, ie, Roots blowers specifically designed to vent to atmosphere and provide very high-pressure differentials safely. As single units, exhausters usually have a much poorer ultimate vacuum than LRPs – typically limited to 200mbar (150torr) – and so for steel degassing duties two stage exhauster sets are needed. The ultimate pressure of these sets is better than those of LRPs.



● **Figure 2** ***Steel degassing module concept***

The big advantages of dry exhausters compared to LRPs are minimal water consumption for cooling and no major waste water disposal problem, no performance dependence on water temperature, and a good, reliable ultimate pressure. However, they are more expensive than LRPs (may be double prime cost), and typically require more installation space. Noise levels of large exhauster sets can also be very high (eg, up to 100dBa without muffling).

Typical steel degassing example

A modern steel degassing plant of nominal 75t heat capacity is designed for VD at 0.67mbar and VOD in the region of 200mbar. The VD specification is 100,000m^3/h at 0.67mbar and 12,000m^3/h at 200mbar. Specifically for the VOD process a large cyclone/bag filtration system is installed upstream of the vacuum system.

To achieve approximately 100,000m^3/h for VD may require four 30,000m^3/h HV boosters on the front row (stage 1), backed by two 14,000m^3/h HV boosters as stage 2. The third stage would be a pair of 11,000m^3/h HV boosters, typically backed by two large LRPs .

Using only the stage 3 HV boosters, plus the LRPs, a reasonably high pumping speed at 200mbar can be achieved for the VOD process. The typical system speed curve is shown in *Figure 1*.

Vacuum systems for VD and VOD of this nature can be considered in a modular arrangement, with the number of modules required being dependant on the size of the steel degassing plant. *Figure 2* shows a basic standard steel degassing module concept which provides approximately 50,000m^3/h pumping speed at 0.67mbar for VD, and approximately 6,500m^3/h at 200mbar for VOD.

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