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Summary
Vacuum degassing (VD) and vacuum oxygen de-carburisation (VOD) are the main processes in secondary steel making. The large volumes of dissolved contaminant gases arising and the generation of metallic fines and oxide dust require robust, high capacity pumping equipment. Today's advanced vacuum dry mechanical vacuum pumping systems are superior to previously-used systems in that they enable better dust handling, increased pumping speed, and reduced operational and maintenance costs.

The need for advanced vacuum pump systems

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 their quality and supplying more special steels.

For reasons of economy these processes are usually conducted on large quantities of molten steel in very large plants, and consequently very large vacuum pumping capacities are usually required. These processes are 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 and expensive amounts of steam, generated by substantial steam raising plant.

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 running costs, maintenance costs, and installation space, 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 steel-making. 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, higher value steel product with more widespread applicability. The two main processes are vacuum degassing (VD) and vacuum oxygen decarburisation (VOD).

Vacuum degassing (VD) The basic VD process usually lasts 15-20 minutes and is conducted at pressures in the region of 0.5torr/0.67mbar. 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

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evacuated. This process can also assist with the removal of lighter, more volatile metal elements (Pb, Sn, As, Sb, Bi, etc.) and sulphur. Residual gas levels in the resulting steel can typically be as low as one ppm for hydrogen. Soft purging with argon at the end of the process can also reduce residual oxygen levels to below 15ppm.

For VD, gas flows of many tens of kg/h air equivalent must be handled at 0.67mbar. This puts the pumping speed capacities required into the 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 (VOD) 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 carbon monoxide (CO) and carbon dioxide (CO_2) which are then evacuated away. To avoid undue losses of chromium the process is usually conducted at pressures of around 60-150torr / 80-200mbar. 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.

Pumping performance requirements
The basic performance parameters and requirements in a typical steel degassing pump system are listed in Table 1.

To meet these high speed vacuum pumping requirements, the system should use an adequate numbers of large high vacuum (HV) Roots booster pumps, staged correctly to achieve sufficient pumping speed while maintaining 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 process, the available site facilities and any customer preferences as follows:

Table 1

Process type	VD & VOD *or* VD only
Heat mass (capacity)	tonnes of liquid metal
Furnace volume	typ. 2-3m^3 per tone
Furnace air leakage	typ. up to 10kg/h (air@20$_o$C)
Initial pump down time to VD	typ. 5-7mins
VD process pressure	typ. 0.67mbar / 0.5torr
VD suction capacity	typ. 1-2 kg/h/tonne (air@20$_o$C)

	typ. 1250-2500m^3/h/tone
VD line diameter	typ. 800-1000mm
VD gas dust load to pump system	typ. v. low
VD gas temperature to pump system	should be <= $60^{\circ}C$
VOD process pressure	typ. 80-200mbar / 60-150torr
VOD suction capacity	Variable
VOD line diameter	typ. 800-1000mm
VOD gas dust load to pump system	can be high if filtration is poor
VOD gas temperature to pump system	should be <= $60^{\circ}C$

Backing pump options

For VD processes the general requirement for backing is to provide reliable and adequate pumping speed at pressures in the region 10-50mbar (7.5-37.5torr).

For VOD processes the requirement for backing is to provide reliable, high pumping speed in the region 200-400mbar (150-300torr), and to be able to tolerate 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 (i.e. provide good pumping speed 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 sized 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 (e.g. 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.

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1) the seal water consumption is large:-
A typical 4,200 m^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 (i.e. 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 very 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.

2) the seal water temperature limits the ultimate achievable:-
Seal water temperature is critical to LRP performance. This is of special concern for VD backing where the LRP must achieve a good ultimate vacuum to avoid stressing the stage three HV boosters (i.e. causing excessive pressure ratio). LRP manufacturers' specifications are usually based on 15^oC 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 LRPs 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, i.e. 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 ultimates of these sets are better than those of LRPs.

The big advantages of dry exhausters compared to LRPs are minimal water consumption (only small quantities needed 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 (e.g. up to 100dBa without muffling).

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Typical Steel Degassing Example

A modern steel degassing plant of nominal 75tonne heat capacity is designed for vacuum degassing (VD) at 0.67mbar and vacuum oxygen decarburising (VOD) in the region of 200mbar. The vacuum system specification is 100,000m3/h at 0.67mbar for VD and also 12,000m3/h at 200 mbar. Specifically for the VOD process a large cyclone/bag filtration system is installed upstream of the vacuum system.

To achieve approximately 100,000m3/h for VD may require four 30,000m3/h HV boosters on the front row (stage 1), backed by two 14,000m3/h HV boosters as stage 2. The third stage would be a pair of 11,000m3/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.

Vacuum systems for VD and VOD of this nature can be considered in a modular arrangement, with the number of "modules" required dependant on the size of the steel degassing plant.