

Quick pump down and pressure control in vacuum steel degassing

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Steelmakers who want to go for quality improvement by vacuum treatment in secondary metallurgy often have only a rough idea regarding the kind of vacuum pump to be selected, the needed suction capacity, the pump down time and the essential selection criteria. For both kinds of vacuum pumps, Steam Ejector Vacuum Pumps (SVP) or dry operating Mechanical Vacuum Pumps (MVP) a lot of information has been given in the recent literature [1-5] such that the choice of suction capacity can be made according to the kind of vacuum process used and the metallurgical possibilities of the RH- or the VD-process.

Keywords:

INTRODUCTION

A general tendency of over-sizing the suction capacity is prevailing with the arguments that the steam ejector cost is nearly the same for medium and high suction capacities, that steam as the drive energy of SVP is of nearly no cost, and that a reserve in capacity has to be made. Such reserve should be made in order to compensate any reduction in pump performance

- by ejector clogging by dust,
- by erosion by water droplets contained in unsaturated steam,
- by seasonal climatic changes and
- by unknown pressure drops between pump and reaction vessel.

MVP- systems do not need any oversizing due to decreasing pump performances. They are build-up in modules and offer both redundancy and extension possibilities, while the capacity losses by gas coolers, cyclone, filter, suction pipe and valves have been investigated and measured [6].

SENSE AND NON-SENSE OF QUICK PUMP DOWN

With the beginning of vacuum technology for steel degassing in the 50-ies MVPs were small and had a low suction capacity. The criterion of **quick pump down** had then been established to be relevant for the pumping performance. But in this respect one has to distinguish between two different vacuum degassing processes, the RH- and the VD-process.

RH-plants have rather small volumes, operate without any active slag and have a very large vessel freeboard permitting to cope with heavy degassing reactions.

It has been reported that a quick pump down to a low pressure of 1 hPa in RH-plants is beneficial for obtaining low carbon contents [7]. The limits of such procedure are given by the metal splashing, but the RH-process offers an elegant way of mastering the intensity of reactions by modulating the melt circulation rate via variable argon flow rates.

VD-plants whether in a ladle, converter or tank, operate under the constraint of restricted freeboard and have to consider an active slag. Therefore rapid pump down to low pressures cannot be done without any risk. VD tanks have rather large volumes and require quick removal of the plant air. However, in order to understand the sense of quick pump down one has to analyse the different steps of the degassing processes to which the pump performances have to be adapted:

- Typically a vacuum treatment cycle starts with the pressure equilibration between a pre-evacuated plant section given by a cyclone, cooler, filter and the pumps themselves and the plant section that is at atmospheric pressure i.e. the vessel and part of the suction duct. This brings the total plant pressure down to 500-700 hPa within a few seconds.
- The first duty of any pump system is then to lower the pressure as quickly as possible until a value where heavy reactions start, i.e. ~300 hPa for unkilld melts or 100 hPa for fully killed melts covered by an active slag.
- In a next step the pump down rate Dp/dt is to be strongly reduced in order to permit the slag to degas and the melt to be liberated from excessive amounts of H, N and volatile metallic elements like Zn and to boil off using the dissolved oxygen or to react with lance-injected oxygen in the VD-OB, VOD or RHO-process. At a constant pumping rate it is not possible to hold a constant pressure since the gas load decreases continuously.
- At the end of oxygen blowing or after 3-5 minutes of boiling off pump down should continue again to about 5 hPa using the pump capacity up to its full extent.
- At that pressure level all degassing reactions become very intensive and all pump sets that are oversized with respect to the vessel or ladle freeboard and the ladle

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covering system must be reduced again in capacity.

- Only at about 1 to 2 hPa, depending on the pump size, the argon flow rate and the way argon is injected, the full pump capacity can be used.

Frequently a quick pump down to 1 hPa or less is requested by the customer and agreed to by the pump supplier in a blank test without the melt. However, this is meaningless for the evaluation of the pump performance, as a fast pump-down can't be realized in practise at a loaded degasser. Next to this, a pump set offering a quick pump down is not automatically strong enough at low pressures.

According to the above process analysis in no case the quick pump down features can be used for any operational practice. This includes argon stirred melts

- in any concentration of dissolved gases (H, N) and volatile metals (Zn, Cd, Mg),
- whether unkilld or fully Al-killd,
- whether covered with slag or not.

Steelmakers have an interest in overcoming any idle time of pump down, during which the melt is cooling down, as quickly as possible and this all the more when the melt size is smaller. But it is not serious to extrapolate the blank test results to the operational practice as it is not serious for a pump supplier to guarantee rapid pump down under operational conditions.

In any pump system, SVP or MVP, the pump down speed is mainly determined by the high pressure pump stages, i.e. water ring pumps (WRP) and boosting ejectors for the SVP-systems, WRP's, endless screws and direct exhausting Roots pumps for the MVP-systems. The suction capacity of the low pressure, high volume pump stages affects the blank test pump down to only a minor extent.

NECESSITY OF PRESSURE CONTROL

The target to remove dissolved gases from a melt quickly and completely leads to the collateral problem of keeping the melt inside the reaction recipient.

Degassing reactions occur suddenly resulting in heavy splashing and in case of presence of an active slag also in foaming and over-spilling.

In RH-plants the gas load can be moderated by reducing the argon flow and thus the circulation rate.

In VD-plants the sudden appearance of degassing reactions at the bath surface could be moderated by intensive

stirring but a very short response time would be required to moderate the reactions by a pressure increase.

One way out of this dilemma is to adapt the pump down curves to the pump (over) - capacity and to the gas load resulting from the plant volume, leaks, argon, metallurgical gases and vapours.

According to the above process analysis the pressure drop rate Dp/dt is reduced in the medium and sometimes also in the low pressure range.

It is not necessary, and because of the sudden start of degassing reactions also very difficult, to hold the pressure constant or to hold the pumping speed constant via a complete control loop.

It should be born in mind that even at a constant pumping speed the gas mass load decreases continuously owing to the decreasing gas content or owing to the decreasing oxygen yield to CO in oxygen blowing processes

However, the pressure drop rate should be reduced significantly and without delay before the full suction capacity is engaged again and reached quickly. The response time of the pumps is therefore an essential criterion.

The mechanical pumps with the lowest inertia moment and the highest ratio of motor power to inertia moment are the best for quick reduction and acceleration of rotational speed for restart of the pumps. These critical features are compared in Table 1 for a volume flow of 500'000 m³/h at 0.67 hPa common for all pump type arrangements. The comparison is made for the pumps engaged in the high volume flow stage at <30 hPa.

Table 1 demonstrates the advantage of a high number of small pumps and the handicap of large pumps when a frequency modulation of pumping speed is required as is the case for all vacuum degassing and decarburising processes. The smaller pumps do not need any "brake" resistance in the frequency converter.

The larger pumps should have a much higher motor power to cope with the inertia moment of the pumps. However this would increase the total moment of pump plus motor. Because of this handicap in motor sizing the larger pumps cannot reach a pressure of 1 hPa quickly when engaged at 30 hPa.

PRESSURE CONTROL POSSIBILITIES

There are different means to reduce the pressure drop rate Dp/dt as listed in Table 2.

MAKE	Type	Typical motor	Nb. of high volume pumps	Installed power of complete pump set	Installed power for high volume stages	Total inertia moment of all high volume pumps	
OLV	WH7000	18.5 kW 2pB5	72	2200 kW	1332 kW	70 kg m ²	100 %
AERZEN	17.15.HV	30 kW 4pB5	30	2400 kW	900 kW	360 kg m ²	520 %
AERZEN	18.17 HV	37.5 kW 4pB3	18	2175 kW	675 kW	590 kg m ²	840 %
EDWARDS	HV 40K	30 kW 4pB5	20	1450 kW	600 kW	660 kg m ²	940 %
AERZEN	19.19 HV	55 kW 4pB3	12	2160 kW	660 kW	980 kg m ²	1400 %
AERZEN	20.21 HV	75 kW 6pB3	6	1950 kW	450 kW	1340 kg m ²	1900 %

Table 1 - Inertia moment of various high volume stage vacuum pumps installed for about 500'000 m³/h at 2 to 0.67 hPa

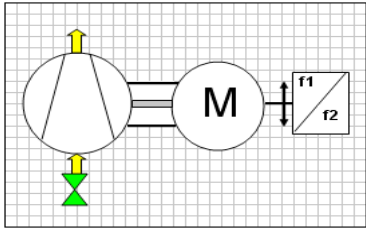
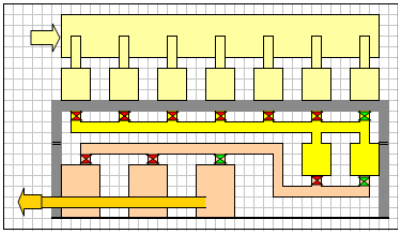
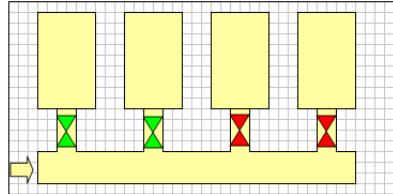
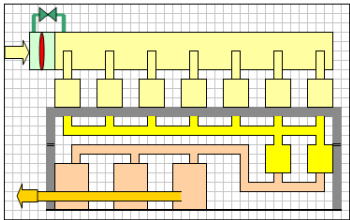
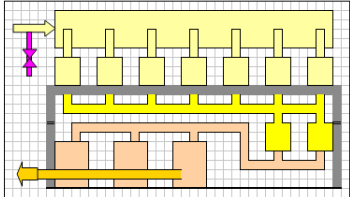
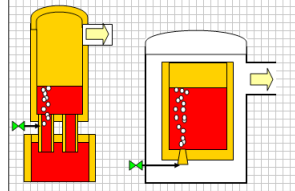
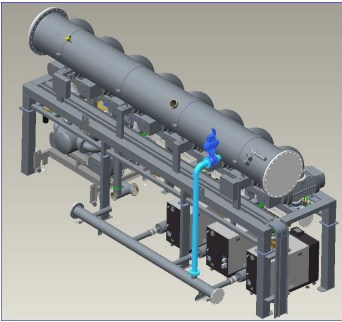
<p>Mode 1: Reducing the rotational speed of MVP or steam flow of SVP, delayed engagement of pump stages or delayed acceleration of low pressure pump stages.</p> <p>Variable speed drives as hydraulic couplings or frequency converters are in use. These means have a limited effect unless used in combination with other modes</p>	
<p>Mode 2: Shut-off of some pumps that operate in parallel in the low pressure stage</p> <p>Needs isolation valves for all considered pumps. Does not deliver a "smooth" regulation</p>	
<p>Mode 3: Shut-off of complete modules or independent lines</p> <p>In case several independent units are installed in parallel. Does not deliver a "smooth" regulation.</p>	
<p>Mode 4: Throttling the gas flow via the main valve or its by-pass valve</p> <p>Requires expensive valve positioner or several parallel valves to cover a wide flow range. High noise level. Increased wear of valve sealing. Smooth re-opening required</p>	
<p>Mode 5: Injection of inert gas at the reaction vessel</p> <p>Energy and inert gas consuming. Frequently done with permanent melt surface observation but lacking precision of control.</p>	
<p>Mode 6: Adjusting the argon flow rate for stirring or circulation</p> <p>Only effective for RH-circulation plants but insufficient and dangerous for VD-plants for which Argon stirring is important in order to avoid oversaturation of any element at the bath surface.</p>	
<p>Mode 7: Recycling off-gas by injecting part of it at the low pressure suction side of the pump system. Frequently used in SVP and easily installed in MVP. Slightly energy consuming as all ballasting modes</p> <p><i>(Picture with courtesy from Oerlikon-Leybold-Vacuum Cologne / Germany)</i></p>	

Table 2 - Possibilities of pressure control during steel vacuum degassing

Process	VD	Tank degassing
Deoxidation	Al killed	at start
Metallurgical gas load	0.18 Sm ³ /t	122 ppm Δ(H+N+O+C)
Argon flow rate (5 litres/min/t)	66 Sm ³ /h	(80 kg/h DAE20)
Nitrogen flow rate	10 Sm ³ /h	(12 kg/h DAE20)
Air leak rate	21 Sm ³ /h	(25 kg/h DAE20)
Peak flow of metallurgical gases	36 Sm ³ /h	(43 kg/h DAE20)
Peak gas load at 100 hPa	4650 m ³ /h	(550 kg/h DAE20)
Gas load at end pressure	105 Sm ³ /h	(125 kg/h DAE20)
Pump set configuration	4 x (8-2-3)	Oerlikon-Leybold-Vacuum
Pump capacity at 0.67 hPa	233'000 m ³ /h	(186 kg/h DAE20)
Pump capacity at 100 hPa	32'600 m ³ /h	(3880 kg/h DAE20)
Primary pump capacity	13'800 m ³ /h	(16600 kg/h DAE20)
Plant volume	575 m ³	Pre-evacuated: 245 m ³
Suction duct diameter	1.6 m	Length incl. bows: 50 m
Filter surface	800 m ²	Filter volume: 2 x 45 m ³
Total pressure loss at 0.67 hPa	0.11 hPa	(16 % of 0.67 hPa)
Effective pump capacity at vessel	200'000 m ³ /h	
Installed motor power	1100 kW	
Peak power absorption	720 kW	At end pressure: 400 kW
Time to reach 550 hPa	8 sec	
Time to reach 100 hPa	173 sec	
Time to reach 0.67hPa	300 sec	in blind test

Table 3: Characteristic data of a 220 t VD - plant with MVP

CASE STUDY FOR LARGE VD-MELTS

The various pressure control modes have been investigated for a large vacuum degassing plant with the characteristic data shown in Table 3.

While pump down in a blind test with the plant air and air leaks as the only gas ballast permits to reach 0.67 hPa within 4.5 min, such pressure would be reached during an uncontrolled and unhindered pump down with the melt, its slag, and argon and nitrogen flow only within 12.5 min. However, during such operation the melt cannot be contained in the ladle due to heavy over-spilling.

This is demonstrated in Figure 1. At 100 hPa when the first heavy degassing reactions are expected to occur the total gas load is 4700 m³/h while the pump capacity is 33'000 m³/h.

As a consequence of this difference between load and pump capacity the continuing evacuation of air from the plant leads to falling pressure and even more violent degassing reactions.

In order to master the heavy degassing reactions it has been tried to reduce the pumping speed by 50 % in the critical pressure range. It can be seen from **Figure 2** that the time to reach 0.67 hPa has been increased slightly, but that this reduction in pumping speed is not sufficient to reach the level of gas load at 100 hPa. Already the primary pumps alone have a higher capacity than would be needed for the gas load.

One is therefore tempted to block a complete module for some minutes (Mode 3 in Table 1).

However, this would only be possible if several modules or

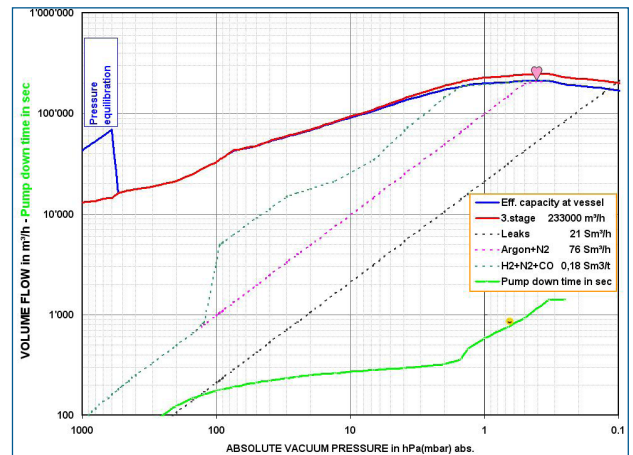


Fig. 1 - Volume flow at the vacuum pump and at the reaction vessel and the different gas loads during a virtually uncontrolled and unhindered pump down.

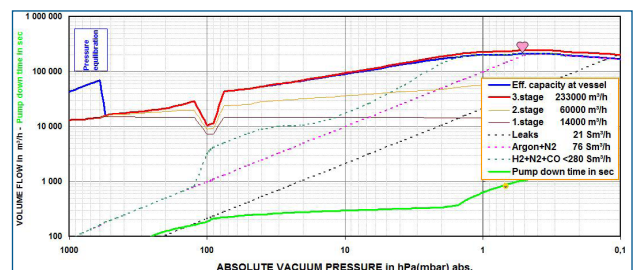


Fig. 2 - Volume flow at the vacuum pump and at the reaction vessel and the different gas loads during a frequency controlled pump down. (Mode 1 in table 2)

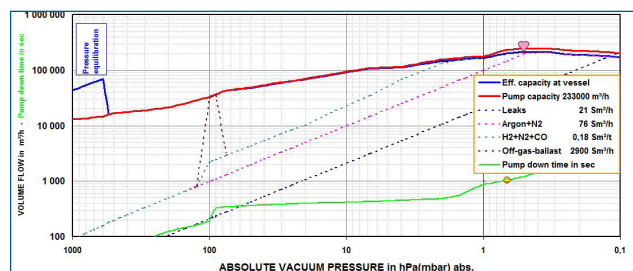


Fig. 3 - Volume flow at the vacuum pump and at the reaction vessel and the different gas loads with a ballast controlled pump down. (Mode 5 or 7 in table 2)

independent lines operate in parallel.

Ballasting by recycling of off-gas (Mode 7 in Table 2) as shown in Figure 3 would be preferable.

Such ballasting by recycling of off-gas requires an adjustable valve and a by-pass pipe and increases energy consuming marginally. A simple shut-off valve could be used in case this pressure control is combined with a frequency modulation.

A simple and cheap way has been tried out successfully by throttling the gas flow by a valve (Modes 4 or 5 in Table 2). This requires smooth valve positioning.

Figure 3 does not show clearly the pump down delay. Therefore in Figure 4 the same volume flow is plotted over the

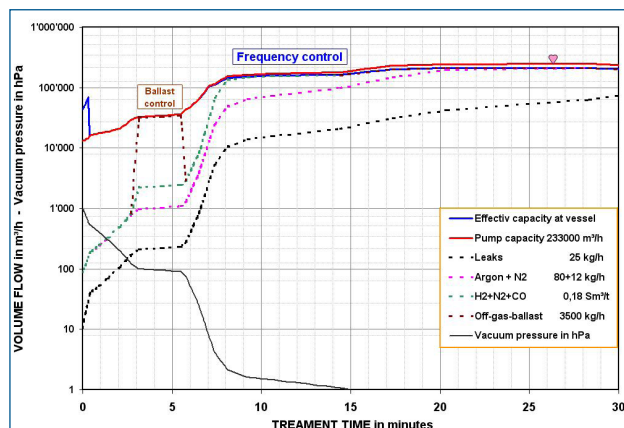


Fig. 4 - Volume flow variation with the treatment time showing the different gas loads with a ballast control at 100 hPa and with a frequency control at < 5 hPa.

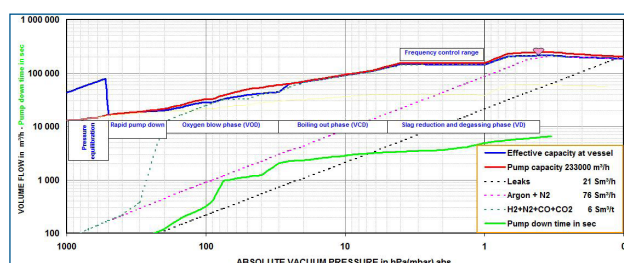


Fig. 5 - Volume flow variation with the treatment time at the vacuum pump and at the reaction vessel and the different gas loads during the VOD-process.

treatment time. In this case the pumps are ballasted with recycled off-gas during 2.5 minutes at 100 hPa. Below 5 hPa the pump capacity is reduced slightly by lowering the frequency by 13 % for about 8 further minutes.

Any flow control at low pressure depends upon the overcapacity of the pump with respect to the gas load, the argon flow rate, the vessel freeboard and the tightening of the ladle by a lid or heat shield.

In other terms a plant with no overcapacity, a large freeboard and an argon flow adapted to the ladle lid does not need any flow control in the low pressure range.

In the oxygen blowing processes (VOD, VD-OB, RHO) pressure control is very simple since the pumping speed adapts automatically to the gas load generated by the decarburisation. Only in case the suction capacity is too high and consequently the vacuum pressure would drop too much, a slight flow reduction by frequency control can be made. The typical VOD situation is shown in Figure 5.

CONCLUSIONS

The various tasks of a vacuum pump set like quick pump down, controlled pump down, short response time while modulating the pumping speed and a low end pressure often lead to over-sizing of the suction capacity in certain pressure ranges.

The requirement of a short pump down time to lowest pressure is neither justified nor useful for the evaluation of the pump set. For tank or ladle degasser systems a short pump down time cannot be realised under operational conditions as this would cause over-spilling.

The aim to reach lowest pump down time realized at empty systems does therefore only increase investment cost into more or bigger pumps, but does not deliver a practical usage.

Establishing a constant pressure via a control loop is not easy since the response time should be extremely short as degassing reactions start suddenly and intensively. However, at a given pumping speed and argon flow rate the gas load is lowered continuously due to the decreasing contents of dissolved gases thus making any pressure control loop unnecessary.

In processes using oxygen injection the pumping speed is in general automatically adapted to the gas load without any special procedure. Also in this case the gas load is lowered continuously due to decreasing oxygen yield.

In order to master the metallurgical reactions there are several possibilities for temporary reduction of pressure drop rate. In a general way recycling of off-gas to the suction side of the high volume pump stage can be applied to all systems and processes.

This permits a drastic and quick temporary reduction of pump down speed as well as a quick achievement of the full suction capacity afterwards.

Beside the systematic reduction of the pressure drop rate in VD plants beginning at a pressure that ranges from 350 to 70 hPa, depending upon the degree of deoxidation, a frequency controlled reduction of the suction capacity at pressures as low as 5 to 2 hPa is recommended depending upon the degree of over-sizing of the suction capacity. This control mode is the more efficient the smaller are the vacuum pumps and the lower is their inertia moment.

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