Off-gas preparation for vacuum pumps

W. Burgmann, J. Davené, J. Laffitte

Vacuum steel degassing plants generate off-gases that are hot, dangerous and dust laden. Therefore they must be cooled down, post-combusted or conveyed in a safe manner and filtered in order to protect the vacuum pumps and the environment.
A risk analysis is necessary for all kinds of vacuum plant regardless the pump system used. This analysis defines the hazard zones and the necessary means to avoid such hazards or a hazard compliant equipment to be installed. The handling of moisture and the protection against the associated corrosion effects are a concern for the dust filters and the vacuum pumps.
The dust load requires special means of erosion protection. The dust abatement and dust extraction from the various gears must be compliant with the dangers of impact by high speed particles, of dust ignition and of aqueous condensates. 50 % of the dust is in a range of 0,2 to 1,5 μm and thus a challenge for filters that combine a high filtering efficiency with a low pressure drop.
All necessary gears in the connection between vacuum pump and metallurgical reaction vessel, that are installed for post-combustion, gas cooling and dust abatement as well as suction duct with all its bows generate pressure losses that could only be compensated by an increased pump capacity. Since this is an important investment and generates higher operation cost one is tempted to take means to reduce such losses. However, this might again require higher pump down capacities. A detailed study involving all parameters is therefore recommended in order to evaluate the various measures to be taken.

Keywords: Steel Degassing - Mechanical Vacuum Pumps - Pressure Losses - Dust Filter - Vacuum Valves

INTRODUCTION

Vacuum steel degassing generates hot off-gas that is loaded with dust as condensed metal vapour and that contains unburned $CO+H_2$ mainly in oxidising processes like VOD, VD-OB, RH-OB. The cooling of these gases and the abatement of dust has advantages for the steam ejector vacuum pumps (SVP) and is a must for mechanical vacuum pumps (MVP).
With the introduction of MVPs for steel degassing a more detailed engineering of the off-gas preparation became necessary since any MVP is only as good as its gas preparation.
Steel degassing plants that were exclusively equipped with steam ejector vacuum pumps did neither have a temperature problem with hot off-gas containing high amounts of dust and CO nor with the pressure losses in the connection between vacuum pump and the metallurgical reaction vessel. However, such plants have severe problems of ejector clogging and thus with maintaining steady performances of the vacuum system.

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To the contrary dry operating MVPs may need a post-combustion device, gas cooling, and always dust abatement in order to assure not to exceed 50 °C and not to exceed 20 mg/m³ of fine dust < 10 μm at the pump inlet. The $CO+H_2$-content in combination with the oxygen content must be outside the flammable range or the equipment has to be built as ATEX compliant without restriction regarding the chemical gas composition and the residual dust content.
This latter condition also applies to water ring pumps used as primary pumps in steam ejector systems.
For all plants there must be a risk analysis defining explosion hazard zones. As the case may be ATEX compliant elements must be used in all endangered areas unless any explosion hazards can be avoided by monitoring the ignition sources or by purging these areas.
Since MVPs represent a rather high investment, particular care should be taken not to annihilate a part of the installed suction capacity by a high pressure loss in the connection line to the vacuum vessel.
With SVPs this latter problem was less stringent since steam as energy source for the vacuum pumps has often been considered to be of very low cost. In fact in integrated steel plants the cost of steam that is available batchwise in excess is defined by the value it has as raw material for the generation of electric energy.
However, nowadays SVPs consume more electrical energy

by primary WRPs, water circulation pumps, sludge pumps and fans of the CO-scrubber and cooling tower, than MVP-sets from any pump supplier.
Also installing dust filters in line with SVPs has been found to be paying off since the maintenance work for ejector cleaning and water filtering is strongly reduced. Furthermore the size of the steam boiler and of the complete SVP system could be reduced thus lowering the investment as well as the running cost.
Last not least constant pumping performance is an invaluable advantage.
In the following the essential features of gas preparation regarding post-combustion, gas cooling and dust abatement are discussed for 3 different steel degassing plant types, VD ladle degassing, VD tank degassing and RH circulation degassing and for all these vacuum processes under reducing and under oxidising conditions.

PRESENTATION OF THE VACUUM PLANTS

Figure 1 shows the typical ladle degassing plant with the vacuum cover directly placed on a sealing flange of the ladle. Such ladles are often in use with inductive stirring [1]. Another type of ladle degassing for smaller heats has not only a vacuum cover but also a lower vacuum chamber sealed directly against the ladle bottom [1,2].
Both systems have been used for the VD-process as well as for the VOD-process.
The vacuum off-take is at the ladle cover (and in parallel at the lower vacuum chamber).
The advantages of such plants are the small space requirement and the small plant volume, while the disadvantages are the limited size of the off-take and the problematic vacuum sealing that might lead to larger leak rates.
Figure 2 shows a sketch of vacuum tank degassing where the ladle is placed into a vacuum tank. This solution requires more space and leads to a larger volume to be evacuated but the vacuum tightness is much more reliable. The vacuum off take is at the vessel in case of stationary vessels, or on the vessel cover in case of travelling vessels. Tank degassing is used for the VD/VCD/VD-OB - and VOD – processes for heats ranging from 6 to 300 t. [2]
Figure 3 shows the vacuum circulation process, also called RH-process. The plant volume is rather small compared to the tank degassing but the leak rate is high because of the build-up of the metallurgical vessel by several parts. The range of melt size for this process is 80 to 350 t.[3]

GAS PREPARATION LINE

In figure 4 a general overview is given for the possible elements of gas preparation shown for a tank degasser but also applicable for a vacuum ladle and an RH vessel.
This starts with a water-cooled heat shield on the ladle as shown in figure 5.
At the vessel exit a refractory lined post-combustion chamber may be installed in case of necessity to complete the gas-combustion or the oxidation of metal vapours. After that a first gas cooling element in the form of an enlarged vertical pipe should be foreseen. Since splashes and very coarse dust particles are withheld in this device it has also been called “slag pot”.
Large amounts of CO are formed during VOD. The hot and dust-laden off-gas is carried at high speed and in turbulent flow to a cyclone where the coarse dust portion is abated.
A narrow VOD off-gas duct is separated from the main duct and is by-passing the main valve during the oxygen blowing phase.

Fig. 1 - Vacuum ladles

Fig. 1 - Siviere di vuoto

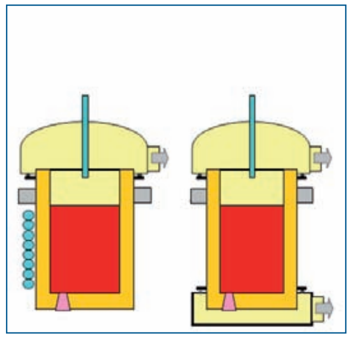


Fig. 2 - Vacuum tank

Fig. 2 - Serbatoio di vuoto

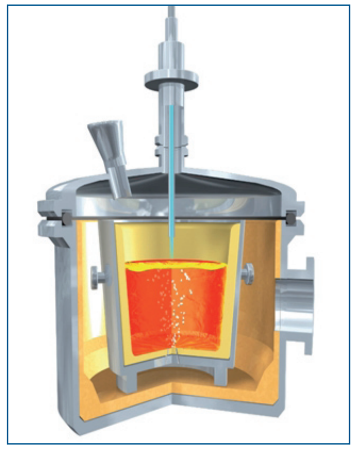
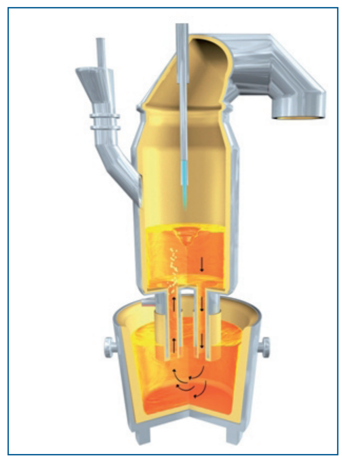


Fig. 3 - RH – vessel

Fig. 3 - Recipiente RH



GAS COOLING

The off-gas temperature from a vacuum ladle or a vacuum tank if measured directly at the exit of the vacuum vessel can reach 300 °C in the centre of the suction duct while the duct surface is cold. But after some meters when the main valve is reached the mean temperature drops down to 60-80 °C thanks to mixing by gas turbulence. At the exit of the RH-vessels this temperature is higher owing to the large amount of heat stored in the vessel lining, but a water-cooled enlarged pipe at the vessel exit acts also as a gas cooler.
When the degassing reactions come to their peak the temperature at the filter entry reaches 100-120 °C and this is still consistent with the heat resistance of the filter sleeves made of polyester needle felt permitting a maximum temperature of 130 -140 °C.
Owing to the strong expansion work during pump down the temperature at the filter exits drops below 0°C generating humidity condensation in the clean gas part of the filter. In the following phase of the degassing process this filter exit temperature climbs up only slightly since the filter structure itself with its low inner flow speed acts as a heat exchanger. In the short VD-cycles of 15-30 min the filter exit temperature reaches 10-20 °C while in the VOD-process cycles of 80-150 min this temperature may climb up to 60 °C.
The narrow VOD duct may also be water cooled.
In case of forced decarburisation of low alloyed steel grades by VD-OB and RH-OB the duration of oxygen blowing is rather short as is the development of heat by CO-post-combustion. The by-pass via a cyclone is then not necessary provided sufficient gas-cooling is cared for to bring the temperature at the filter inlet to below 60 °C and the filter has a cyclone-like raw gas inlet.
Some vacuum pumps need water cooling for the bearings, the oil chamber and the most modern pumps have also a water-cooled potted motor, permitting operation at lowest frequencies [5]. Some multistage vacuum pump sets need inter-stage water-air heat exchangers that are a must for all pre-inlet cooled Roots pumps. In addition to all that, most screw compressors have a water-cooled pump casing.
The target for these cooling gears is protection of the equipment. To a minor extent also the lower explosive limit (LEL) is brought to higher $CO+H_2$-concentrations.

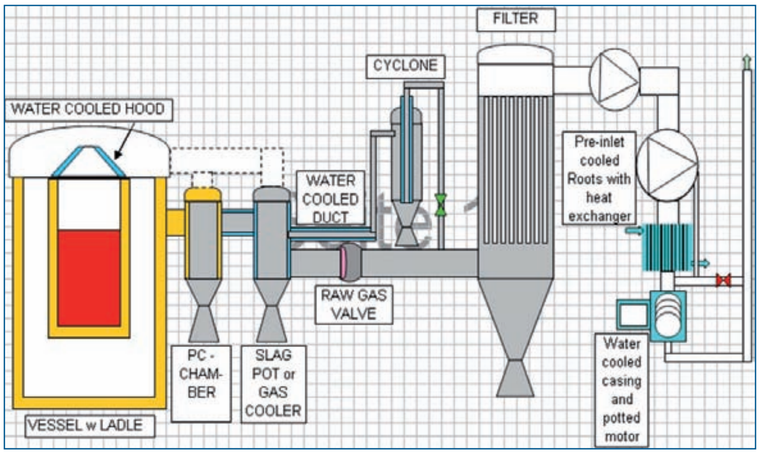


Fig. 4 - Sketch of a universal off-gas preparation line showing the various possible elements for post-combustion, gas cooling and dust abatement.

Fig. 4 - Schema di una linea universale di preparazione dei gas di scarico che mostra i vari elementi possibili per la post-combustione, il raffreddamento del gas e l'abbattimento di polveri

Fig. 5 - Box-type water cooled heat shield with smooth inner surface made exclusively from black steel. [4]

Fig. 5 - Schermo termico raffreddato ad acqua del tipo a scatola con una superficie interna liscia fatta esclusivamente di acciaio nero.

POST-COMBUSTION

Hydrogen gases (H_2) and carbon monoxide (CO) are formed in all vacuum degassing processes, even in fully deoxidised melts. In this latter case CO is the issue of MgO – reduction by carbon. The concentration of these gases may be in their explosive range. Explosions could therefore occur in case the minimum oxygen concentration (MOL) is exceeded. Air leaks are only a very small source of oxygen and in general they are far from generating any explosive mixture.

However, air leaks are not the only oxygen source. During oxygen blowing via a top lance the oxygen jet is not coherent enough to avoid that some oxygen reacts with the rising CO from the melt thus generating a post-combustion of CO to CO_2. This exothermic reaction generates a lot of heat so that according to the chemical equilibrium a mixture of the 3 involved gases CO, CO_2 and O_2 leaves the reaction vessel. On their way to the vacuum pump they cool down below the ignition temperature. They can react again when brought to a higher pressure and to a high-temperature ignition source.
Since the gas mixtures cannot be kept outside the flammable range and dilution by nitrogen would require tremendous amounts of dilution gas and thus very strong vacuum pumps, the plant supplier or the end-user has to establish an Ignition Hazard Assessment document according to EN 13463-1 and a compliance document for Constructional

Safety according to EN 12463-5 as well as to install a continuous monitoring of ignition sources and purging.
A water-cooled ladle cover (Figure 5) helps to reduce the excessive temperature generated by the internal post-combustion but in many cases this is not sufficient.
There is the possibility to perform a controlled post-combustion outside the vessel in a separate chamber. Such chamber must be kept at a certain temperature range to ensure positive ignition and must remove enough energy to allow the CO to become post-combusted. This requires a certain residence time inside the post-combustion zone.
Besides the flammable gases CO and H_2 also metal vapours can generate problems. Under reducing conditions normally prevailing in the VD process these vapours cool down before they oxidise in a strongly exothermic reaction.
It can be observed that metal condensates burn during venting at the end of a treatment cycle.
In case of larger leakages at the vessel seal this combustion of metal vapours can generate very high off-gas temperatures of up to 800 °C. For the protection of filter and vacuum pumps gas cooling is then compulsory. In case only the metal vapours like Zn are to be oxidised without aiming at a low pressure degassing an excess of air as artificial leak may be used and a vacuum pressure of 100 hPa would be sufficient [6].

HUMIDITY

There are many sources of humidity inside a vacuum plant for steel degassing. Some of them can be avoided others not. Such sources are:

- moisture from refractory mortar or unshaped refractory masses,
- water used as protection of the main vessel sealing,
- humidity as monomolecular layers inside the pores of refractory lining,
- water dissolved in the slag as (OH)-,
- oxidised hydrogen that escapes from the melt,
- natural humidity of the plant air.

Only the 2 first sources can be avoided, but the plant air always contains ~2 % of moisture depending upon the climatic conditions. Also a desulphurising slag contains over 1000 ppm of water such that for a 100 t plant with 15 kg/t of slag and a plant volume of 300 m³ about 9 -10 kg of water are to be handled.
Water is not only a source of hydrogen pick-up by the melt but it could also be very detrimental to the filter sleeve material and other plant equipment.
However, these latter problems can be solved by a suitable pump design and material selection within the vacuum pump set.
Avoiding hydrogen pick-up of the melt and its degassing to very low values is the target of most vacuum processes in metallurgy.
The moisture of all sources is evaporated under the effect of low pressure. But by the effect of expansion during quick pump down the off gases cool down to below 0°C. Ice formation has been observed in case the degassing cycle is interrupted at an early stage. Also condensation cannot be avoided on the colder parts of the vacuum plant. Such condensation is not harmful if it does not occur in combination with fine dust deposits and with gaseous components that generate a high acidity of such condensates.
The sensitive elements of any bag filter like bag cages and other elements of the clean gas zone of the filter are made of corrosion resistant material either by coating or by selecting a suitable material.
The sensitive parts of the vacuum pumps are purged during this critical pump down phase (as well as during venting at the end of cycle). In the low pressure phase of any vacuum treatment cycle the condensates evaporate again if they are not trapped in any deep point. The most critical items in every pump set are the water-cooled items such as water-air heat exchangers. They should be made of corrosion resistant pipes in order to resist to the high acidity of aqueous condensates and case wise to a bad chemical composition of the cooling water.
The entire pump set should be kept above the dew point of the condensate. This is of particular importance on the high pressure side of the pump set.
Pump sets that are effectively dry operating are on the market [5,7]. They need no water cooled heat exchanger and all moisture and residual dust are continuously expelled outwards.

DUST ABATEMENT

Dust is generated by the evaporation of metallic melt components and of sub-oxides from the slag. Splashes from the heavily stirred melt and from the strong degassing reactions are considered here as being part of a coarse dust fraction.
Metal vapours condensate and precipitate on colder plant elements. Even at room temperature they oxidise as far as there is enough oxygen available.
In most cases the dust to be abated is composed by a pyrophoric mixture of grains, originating from Mg, Mn, Zn and Fe, in the range of 0,1 to 5 µm (50 % between 0,2 and 1,5 µm depending on the process and upon the grain size measurement method).
The wide range of grains sizes, the wide range of temperatures inside a vacuum plant from metallurgical vessel to the pump set and the wide range of gas density that occurs during a vacuum treatment make it advisable to care for different steps of dust abatement.
A first step would be to install an enlarged vertical suction pipe portion close to the metallurgical vessel. Such device is called “slag pot” for its facility to collect the coarser dust portion. During pump down the dust particles are carried by a high mass flow of gases.
Their speed would be reduced by the enlarged section and by the temperature drop and a good portion of such dust

will be collected in a funnel outlet of this slag pot.
Under oxidising conditions, i.e. when oxygen is injected during the vacuum treatment, the operating pressure is rather high in the range of 150 to 50 mbar and the formation of dust is strongly increased by two factors:

- The oxygen jet impact zone is at a higher temperature than the mean melt temperature thus favouring the evaporation of all melt components, mainly Mn but also the basic element Fe.
- The jet favours also the formation of splashes.

As a result the amount of formed dust is increased by a factor of 20-50 with respect to the vacuum processes under reducing conditions like VID, VD, VCD and RH and the mean grain size is also pushed to higher values.
During the blowing phase with its associated conditions of temperature, pressure and dust concentration the off-gas should be conveyed via a narrow duct to a cyclone and cooler before entering a bag filter. The sizing of this duct aims at maintaining a high gas speed with a turbulent flow in order to avoid dust deposits in the duct and to keep the flow speed high enough at the cyclone inlet.
The dust cyclone does not claim to be a perfect dust abatement device but the coarser dust portion with a grain size >1,5 µm will be retained by about 30 % and will not load the bag filter. Gas cooling inside the cyclone itself is not sufficient for rendering the gas temperature harmless for the conventional bag filter material, but the inner outlet pipe of the cyclone may be conceived as an easily cleanable pipe type water-air heat exchanger as indicated in Figure 4.
The use of high temperature resistant filter material would not solve the temperature problem. Even in case such filter material withstands a gas temperature of 600 °C, it will not resist any larger hot particles that might escape the cyclone and that are conveyed at a high speed of 40-70 m/sec in the main duct. They would pierce easily any filter material by their impact energy. The same material would not resist any dust ignition temperatures exceeding locally 1800 °C.
Last not least it should be noted that the acceptable off-gas temperature for any mechanical vacuum pumps never exceeds 50-60 °C.

The bag filter should be conceived for the multiple targets

- to withhold the maximum of fine dust,
- to avoid larger pressure losses,
- to keep the plant volume in a reasonable size,
- to assure a long life of the bag material,
- to be easily cleanable,
- to avoid any dust ignition,
- to collect the abated dust,
- to assure a dust extraction without any operational constraint.

In order to fulfil the above requirements many dust filters are offered on the market.
One ideal design is described below:

- Tangential gas inlet permitting a slight cyclone effect and avoiding the direct gas flow towards the bags without direct hitting by the dust particles,
- Narrow arrangement of the bags thus reducing the filter volume (A filter volume of 75 m^3 including clean gas space and collecting funnel should permit a filtering surface of 450 m^2 with a 60 mm distance between the bags),
- Geometric filtering surface 200-450 m^2 with bag material of 1-2 mm thickness thus generating an effective filtering surface of up to 1000 m^2 including the pore channels of the bag material,
- Bag material made of polyester needle felt resisting 130 °C gas temperature and being easily cleanable by repeated pulsejets,
- Conductance of the sleeve material of 0,1-0,2 litre/sec/cm^2 at 0,3-0,8 hPa,
- No dust deposit in the collecting funnels thus avoiding any acoustic vibration means (funnel angle > 60 °),
- Automatic pulsejet cleaning with nitrogen,
- Venting of the filter with nitrogen in between the heats not necessary thanks to a tight raw gas isolation valve,
- Corrosion resistant material in the clean gas chamber (bag cages, holding plates etc.) where the risk of aqueous condensation with high acidity exists,
- Dust extraction possible at any moment of the vacuum treatment cycle either at atmospheric pressure by a collecting bin or by pneumatic conveying from a pressure vessel.

PRESSURE LOSSES

Pressure looses occur in different elements between the pump set and the metallurgical reaction vessel.
These elements are

- suction ducts of various diameter, length and inner roughness
- kind and number of pipe bows
- various kinds of isolation valves
- post-combustion chamber,
- slag pot,
- cyclone,
- dust filter whereas pressure drops are caused by
  - deviations of the gas flow at its inlet,
  - filter cloth with its dust cake,
  - protection grid at its clean chamber exit.

The pressure drop in the suction pipe is defined by the formula [8,9]

$\Delta p = \xi * (0{,}5 * \rho * v^2) * (L/ D)$, with
Δp pressure drop in hPa,
ρ gas density in kg/m^3,
v gas velocity in m/sec,
L pipe length in m,
D pipe diameter in m,
ξ resistance coefficient.

This resistance coefficient depends upon the kind of flow (laminar or turbulent) and upon the inner pipe roughness.

As an example for a volume flow of 100000 m³/h at 1 hPa and 100 °C in a suction pipe of 1 m diameter, a length of 100 m and an inner roughness of 0,1 mm the pressure loss would be only 2 Pa or 2 %.
However, this is not the only pressure loss to be considered. The other elements as mentioned above generate much higher pressure losses.
For these elements the above formula looses the L/D - member and the resistance coefficient is known under other Greek letters (λ or ζ).
In Table I some frequently used resistance coefficients are listed.
Not all of the above listed valves are suitable for the vacuum processes that all generate hot and dust-laden gas while the gas flow rate is high. The valve gaskets therefore must be protected against the impact of high speed dust particles otherwise the tightness of this valve would suffer leading to a filter bag ignition or reduced lifetime of the filter bags.
Figure 6 shows a straight flap valve with gasket protection device that fulfils the most severe requirements in metallurgy combined with a nearly zero pressure loss. A variety of this straight valve is made as a right angle valve with inner deflector sheet.
The distribution of the various pressure drop sources is shown in Figure 7 for different pressures. It can be seem that there is no significant pressure drop generated by the selected straight flap valve (right side).
In many plants that are equipped with a dish type valve the pressure loss for this element is ~ 3 % thus leading to a total pressure drop of ~ 16 % at 0,67 hPa.(left side)
The pressure drops generated by the small VOD-suction line and the cyclone with gas cooler may reach high values of 10-20 hPa. But such losses are not detrimental to the performances of the process since the blowing phase operates in a pressure range from 200 to 50 hPa.

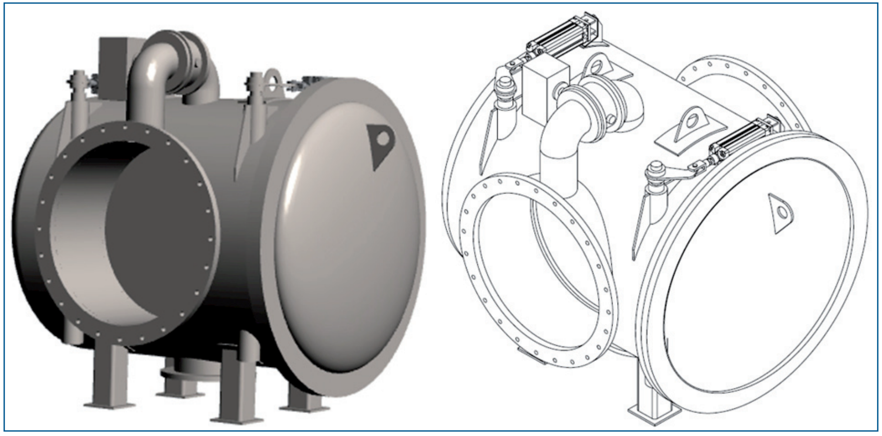
Item	Mean	Range	Conditions	Source
Pipe	0,04	0,02-0,05	Roughness depending	[8]
Smooth bow	0,16	0,14-0,30	90°, < DN 800, R/D =2	[8]
5-segment bow	0,20	0,18-0,30	90°, > DN 800, R/D =2	[8]
Grid	0,25		Wire 1,5 mm, spacing 10 mm	[8]
Gate valve	0,25		VAT / Z+J	[9] [10]
Conical gate valve	0,30			[9]
Butterfly valve	0,25	0,16 - 0,80	EBRO, SAPAG, KSB etc.	[8] [9]
Oblique dish valve	0,70	0,6 - 2,5		[9]
Straight dish valve	5	5 - 6	DN>800 ASO - design	[9] [11]
Straight dish valve	3,5	3 - 4	MTAG-CLESID - design	
Right angle dish valve	6	5 - 7	Sharp edged, restricted opening	[8]
Right angle flap valve	1,3	1,1 - 1,8	CLESID - design	[8] [9][10]
Straight flap valve	0,05		CLESID - design	[10]

Tab. I - Resistance coefficients ξ, λ, ζ of various elements

Tab. I - Coefficienti di resistenza ξ,λ,ζ per vari elementi

Fig. 6 - Straight flap valve for low pressure loss with gasket protection [10]

Fig. 6 - Valvola a falda dritta per una perdita bassa di pressione con guarnizione protetta



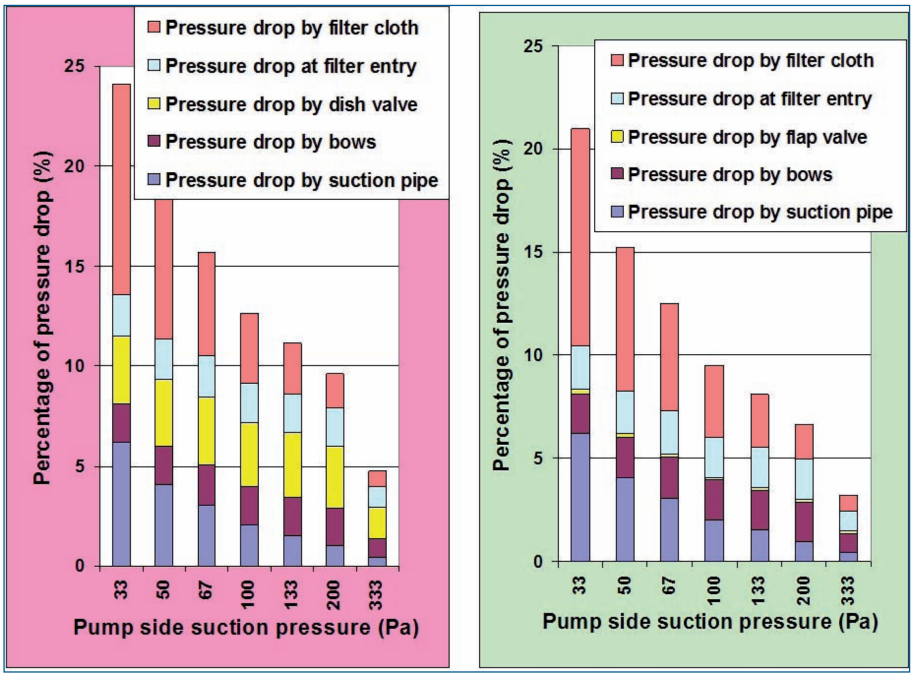


Fig. 7 - Pressure drop by various structural elements between pump set and metallurgical vessel and the influence of pressure (Q=100000 m³/h, DN1000. L=100 m, 6x90° bows, 400m² filter, dish valve pink left, flap valve green right)

Fig. 7 - Perdita di pressione da vari elementi strutturali fra unità di pompe e recipiente metallurgico e influenza della pressione. (Q=100000 m³/h, DN 1000, L=100m, 6 curve da 90°, filtro da 400 m², valvola a piattello a sinistra in rosa, valvola a falda a destra in verde)

RELATIONSHIP BETWEEN PRESSURE LOSS, PLANT VOLUME AND EFFECTIVE SUCTION CAPACITY

The selection of the required suction capacity at a given pressure determined at the reaction vessel has to take into account all losses in suction capacity that might occur by pressure drops, clogging and wear phenomena as well as climatic changes. For dry operating mechanical vacuum pumps only the pressure losses have to be considered. The choice of the filter plays an important role since in many cases it causes over 50 % of the losses.
In the run for reduced pressure losses one is tempted to enlarge the filter surface and to select larger duct diameters. However, this generates larger volumes to be evacuated thus requiring larger pump capacities during the pump down phase.
An excessive large suction pipe diameter could lead to a slow laminar flow whereas a turbulent flow is recommended to avoid dust deposits in the suction pipe.
A larger filter volume (by a larger surface) would of course increase the pre-evacuated part of the total volume thus permitting a much shorter pump down in the upper pressure range, but still a larger volume has to be brought to low pressure.
With this respect one has to look at the predominant operational task of the vacuum plant.
On the one hand a short pump down time is requested and on the other hand the maximum suction capacity at low pressure is wanted, while always the minimum of cost in investment and operation is preferred.
VD-plants and RH-plants for degassing of Al-killed steel require a quick pump down to 100 hPa, a controlled pump down at medium pressures to master heavy reactions and a suction capacity to cope with the metallurgical gas load at low pressure.

Melt size	t	200		
Process		VCD		
Injected Argon	m³/h	60		
Air + N2 -leaks	m³/h	18		
H, (OH), N, C, O to be removed	ppm	920		
Cycle time	min	30		
Suction capacity required at vessel at 0,67 hPa	m³/h	140700		
				Δ
Pipe diameter	m	1,3	1,2	- 0,1
Pipe length	m	50		-
Number- of 90 ° -bows		8		-
Number of filters		2	1	1
Apparent outer filtering surface	m²	900	450	- 450
Total pressure loss	%	13	23	+10
Suction capacity required at pump at 0,67 hPa	m³/h	158800	173800	+15000
Total plant volume	m³	409	334	- 75
Pre-evacuated volume	m³	188	125	- 63
Pump down to 0,67 hPa in blind test	sec	334	257	- 77

Table II - Example calculation for 2 different connection layouts

Tab. II - Esempio di calcolo per 2 layout differenti

In the case of VCD or VD-OB for vacuum deoxidation or for decarburisation the evacuation must only by quick down to 300 hPa and the need of pressure control in the medium range is even more pronounced.
In RH-OB - plants for decarburisation to lowest C-contents, a very quick pump down to a low vacuum pressure has been found to lead to lower C-contents [12].
A model can be established that considers the 4 main operational parameters that define the characteristics of the pump set that is to be selected. These are

- the pressure losses,
- the plant volume,
- the pump down time and
- the effective suction capacity required at the reaction vessel.

The evaluation of different, sometime counter effective, parameters is the more important the larger are the melt sizes are to be treated.
A model may permit to achieve the optimum in investment and operation cost.
Table II shows an example of layout calculation for 2 different solutions that would have to be evaluated.
In this example one has to evaluate the slightly higher pump investment cost of ~110000 € (at a base of 7-8 €/(m^3/h)), against the minor investment for filter, valve and duct material and the slightly shorter pump down time.
The smaller filter surface is supposed to have no effect on the residual dust content, the specific gas load of the filters being always close to or below 0.1 (m^3/sec)/m^2.
Another example is given for the RH-OB-plants. In many cases a multipurpose oxygen blow lance needs to be held free by a large nitrogen flow. This is of course substantial inert gas ballast that requires additional suction capacity. Table III shows the influence of this high ballast on the pump capacity, plant volume and pressure loss.
This table demonstrates that an amount of ~1,4 M€ could be saved if another way of lance design and protection could be found or in case other permanent gas loads like leaks could be reduced significantly.
Mechanical pump sets are not made available by the pump manufacturers in any size but only in skid multiples of 28000 m^3/h, 40000 m^3/h, 64000 m^3/h or 120000 m^3/h or in line multiples of up to 75000 m^3/h.
In all considered cases the value of redundancy and of the filter and of the pump set have to be added to the above mentioned capacity considerations.

				Δ
Injected Argon (8 litres/min/t)	m^3/h	120		-
Air leaks , + injected N_2	m^3/h	220	120	-100
H,(OH), N, O, C to be removed	ppm	1440		-
Cycle time	min	20		-
Suction capacity required at pump at 0,67 hPa	m^3/h	697000	491000	-206000
Selected suction capacity	m^3/h	706000	513000	-192000
Suction pipe diameter	mm	2300	2000	-300
Total plant volume	m^3	887	622	-265
Pre-evacuated volume	m^3	583	400	-184
Total pressure loss (at 0,67hPa at pump side)	%	24		-
Investment saving on pump side	k€			-1400

Table III - Example calculation for 2 different nitrogen ballasts in a 250 t RH-OB-plant

Tab. III - Esempio di calcolo per 2 carichi d'azoto gassoso in un impianto RH-OB per 250 t

CONCLUSION

Pressure losses between any pump set and the metallurgical reaction vessel cannot be avoided, while the distance length between these two units is not the main critical item.
Such losses should be compensated by a larger suction capacity in order to obtain the desired operational pressure at the reaction vessel.
Pressure losses can be minimized by selecting large section elements that might however, lead to longer pump down times and thus annihilate the effect of the larger installed pumping performances in cases where a short pump down time is of interest.
Modern vacuum valves can reduce the pressure loss without any negative side effect.
A detailed study should therefore be made evaluating all parameters like cost of installed pump capacity, cost of all connection elements, like post-combustion chamber, cyclone, coolers, filter, main valve, pipe and bows, cost of layout in order to reduce the number of pipe bows, the pump down time, the break down concept and the operating cost.
Such study is the more important the larger are the heat sizes and the inert gas flow rates as in the RH-OB-process.
Modifications at the RH-OB-layout may be paying off since in the larger RH- plants frequently the pressure losses are such that over 50 % of the installed energy is annihilated and not useful for the metallurgical target.

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PREPARAZIONE DEI GAS DI SCARICO PER POMPE DI VUOTO

Parole chiave: Acciaio – Decarburazione - Affinazione - Ecologia - Energia - Processi

Gli impianti di degasaggio d'acciaio sotto vuoto generano gas di scarico caldi, pericolosi e ricchi di polvere, che per proteggere le pompe e l'ambiente devono essere raffreddati, resi esausti, trasportati in maniera sicura e filtrati.
È necessaria pertanto fare una valutazione del rischio per ogni tipo d'impianto di vuoto indipendentemente dal sistema di pompe scelto. Tale analisi definisce le zone pericolose, le misure necessarie e gli opportuni dispositivi di sicurezza da installare per evitare accadimenti dannosi alle persone, agli impianti e all'ambiente.
La corretta gestione del tasso d'umidità e la protezione contro gli effetti di corrosione acida deve essere altrettanto attentamente valutata nella progettazione dei vari componenti impiantistici per la salvaguardia degli impianti di filtrazione e delle pompe, così come il carico di polvere contenuto nei fumi aspirati richiede opportune misure di protezione contro l'erosione meccanica generata dalle particelle che viaggiano ad alta velocità, contro l'ignizione della polvere e contro condensati acquosi.
Poiché il 50 % di queste particelle ha un diametro tra 0,2 a 1,5 μm bisogna che siano progettati i filtri in modo che garantiscano un'alta efficienza di filtraggio con la minor perdita di carico.
Tutti i componenti impiantistici installati nel collegamento tra le pompe di vuoto e il recipiente di reazione metallurgico hanno la finalità di ottenere la corretta postcombustione, il raffreddamento del gas, e l'abbattimento della polvere ma, unitamente al condotto d'aspirazione con tutte le sue curve, generano perdite di carico che dovrebbero essere compensate da un'aumentata capacità aspirativa. Quest'ultima rappresenta una voce molto importante dell'investimento e comporta anche costi operativi più elevati, pertanto un'adeguata progettazione deve essere finalizzata a ridurre tali perdite di carico senza che ciò comporti una capacità di discesa del vuoto troppo rapida. Per questo motivo uno studio corretto del progetto, che valuti con attenzione tutti i parametri sopra menzionati, è fondamentale per raggiungere il miglior risultato metallurgico al minor costo di investimento e quindi di esercizio.