INNOVATIVE VACUUM-TANK DEGASSING TECHNOLOGIES: WELL-ESTABLISHED METALLURGICAL PERFORMANCE FIGURES ACHIEVED BY USING DRY MECHANICAL PUMPS*

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Abstract

With increasing demands for highly performing and at the same time efficient and running-costs saving vacuum-degassing equipment, dry mechanical pumps have been confirmed a proper choice to completely fulfill the expectations of steel-making companies worldwide. Regarding the production of both special carbon steel and stainless steel grades, the usage of mentioned pumps allowed reaching simultaneous remarkable results from different viewpoints in various Danieli worldwide installations (treating up to 200 t of liquid steel). As a matter of fact, in front of the replacement of a widely spread and renowned technology such as steam-ejector pumps with the recently developed technology embodied by the dry mechanical pumps, well-established metallurgical performances in terms of carbon-hydrogen-nitrogen-sulphur removal have been repeatedly attained while meeting at the same time the client's expectations concerning, for example, running-costs and push-button availability. Additionally, thanks to the very flexible, modular, redundant and maintenance-friendly equipment design, random problems occurring to the singular mechanical pumps can be easily solved without affecting the VD-VOD plant availability and metallurgical performance. With a particular regard to the VOD process, a very short overall process-time has been repeatedly performed (averagely less than 58min under-vacuum time at ChMP1) while guaranteeing the expected required quality of the final refined stainless steel. Moreover, in several VOD installations (ranging from 6 t up to 110 t of liquid steel) an efficient automatic process control such as dynamic pressure-regulation during oxygen-blowing has been attained thanks to the controllable variable-speed drives with which each mechanical pump is provided.

Keywords: Dry mechanical; Pumps; VD; VOD; Process; Stainless steel; Cost saving; Environment.

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1 INTRODUCTION

Compared to a traditional degassing system provided with SVP, VD equipments provided with MVP underwent some modifications/optimizations in order to perfectly fit the new vacuum generating system requirement for smaller leakages and dry off-gas and to allow simple and fast maintenance. Thanks to the adopted solutions that are described in detail in this paper, for a given MVP-based degassing system it was possible to get at the same time the required steel metallurgical properties, the expected plant productivity and a considerable running-costs saving in comparison to a similar standard designed SVP degassing system.

2 OPTIMIZATIONS INTRODUCED IN THE SUCTION LINE

Since MVP cannot tolerate a too high dust load, the VD equipments provided with such pumps necessitate a properly designed textile filter to be installed in-line and working all the time when the MVP are running. For a VD process, the mere presence of a standard cyclone with off-gas cooling effect is enough for providing at the same time first dust filtering and a minimum gas cooling effect in order not to exceed the maximum allowed inlet temperature for both filter and pumps. If considering VOD equipments, an additional gas-cooler is provided upstream of bag filter. Equipment layouts like the one (simplified) reported in Figure 1 have been installed in several Danieli VD-VOD plants equipped with MVP: the reported filter is a double-body filter which is very convenient when very high productivity is required and/or the productivity cannot be affected by the filter bags maintenance activities.

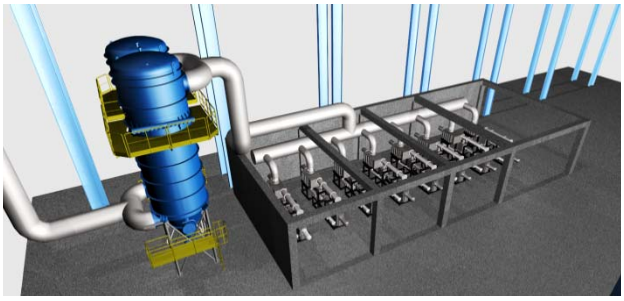

Figure 1: Example of a MVP-based VD plant equipped with double-body textile filter upstream the MVP

As it is indicated in Figure 1, a dust detector has been installed downstream the textile filter: thanks to its installation the filter bags condition is continuously monitored and whenever the dust alarm threshold is reached (meaning that the dust flow passing through the bags is too high to be borne by the MVP) a pop-up immediately appears on the VD/VOD-HMI warning the VD/VOD-operator that the filter bags are excessively worn and dedicated maintenance is needed. In order ~~to~~ make the pump-down shorter, it is normal and well-established practice to automatically pre-evacuate all the suction line (textile filter included) till the MSOV before each VD treatment: consequently, when opening the MSOV at the beginning of a VD-VOD cycle, the gas-flow passing through this valve is initially supersonic due to the high pressure difference between the degassing tank side and the filter side. This high gas flow speed diminishes the MSOV lifecycle. In consideration of this, a further introduced equipment improvement is embodied by the bypass valve (displayed in detail in Figure 2): installed in parallel to the MSOV it is much smaller than the MSOV and it is opened during the first seconds of pump-down during the treatment allowing a further protection of both filter bags (which in this way experience much smaller mechanical stresses) and MSOV. This way the bypass valve undergoes wearing instead of the MSOV, but contrarily to the latter its replacement is much easier and faster and furthermore it's much less expensive.

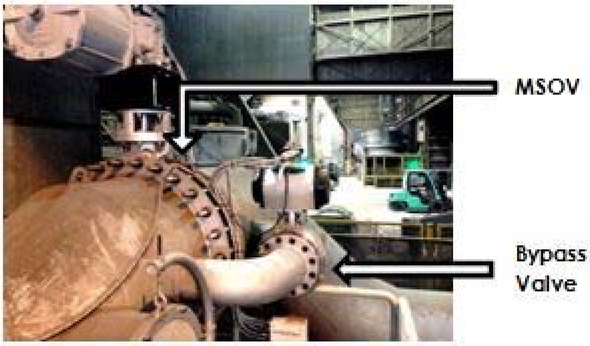

Figure 2: Bypass valve installed parallel to the MSOV

Pin-hole video camera management

Considering the much smaller MVP designed suction capacity in comparison to the SVP standard-designed one provided for the same heat size, a particular attention has been paid to the pin-hole camera purging fluid management: in order to minimize any additional load to the MVP, its flow has been reduced to the minimum sufficient level that still guarantees a proper camera protection from steel-slag splashing. This purging flow optimization allowed the installation of even two pin-hole cameras on the degassing cover and this way the final level of vacuum reached during each VD-VOD treatment was only slightly affected: one camera was installed nearby the vertical axis of the degassing tank cover and the other one close to the horizontal axis of the same cover (see Figure 3, where both views of the two installed cameras are displayed for ABS-Sisak VD-plant). This way the bottom stirring flow and the slag foaming phenomena were effectively and quickly managed and instantaneously optimized during each degassing treatment.

Figure 3: View from horizontal camera (left picture) and vertical camera (right picture)

Optimization of textile filter maintenance and its bag cleaning

The textile filter is one of the most critical parts of the VD/VOD equipments provided with MVP. The pyrophoric metallic dust that is continuously depositing and building up on its bags surface during the vacuum treatment is extremely reactive and can seriously damage the bags when ignited through the contact with the air. For this reason the filter automatic cleaning (and repressurization when there is a production stoppage) is carried out, using nitrogen, at the end of every vacuum treatment. In fact, a possible dust igniting source is the air present inside the degassing tank that is evacuated during the treatment pump-down. In order to guarantee a constant bags-cleaning efficiency, the cleaning nitrogen pressure at the manifold located just before the pulse-jet valves is continuously monitored by means of a pressure transmitter. When this pressure drops below a given threshold, a dedicated pop-up alarm generates on the VD/VOD-HMI.
The textile filter body is provided with a movable cover on its top for making the maintenance as safe, fast and user-friendly as possible. In fact, in such a way, the internal clean-side part of the textile filter can be easily accessed by the maintenance

personnel while staying on open-air instead of entering into a confined space through a man-hole. By means of a dedicated jib-crane, the filter cover can be quickly removed and the filter-bags can be easily and quickly inspected and, if necessary, changed in the shortest time.

Dry-mechanical vacuum pump systems

In Danieli VD/VOD plants the pumps are installed following different layouts and for each of them a customized maintenance and monitoring procedure is developed. Two different types of MVP and their relative layouts are shown in Figure 5.
As these drawings are illustrating, the MVP systems have been designed with the intention to maximize their flexibility from a maintenance and process point of view and this was made possible thanks to their modular, redundant and easily accessible installation together with a dedicated automation. In case of appearance of a pump malfunction, depending on the specific pumps layout configuration, either the singular pump is isolated from the remaining pumps by closing both pump upstream and downstream on/off valves or the pump pertinent skid is isolated from the system by closing its skid valve. It must be highlighted that even when working with one or more pumps isolated due to temporary malfunctions, the final quality of steel can be anyway guaranteed depending on the suction capacity design of the pumps system. In consideration of this, the best MVP design solution, which optimizes the pumps availability and maintenance activities and therefore contributes to have constantly and reliably high equipment productivity, is the one including spare suction capacity in terms of hot-standby pumps. This solution was chosen for the ABS-Italy plant, where out of the 6 provided pump skids, one is supposed to work in hot standby.

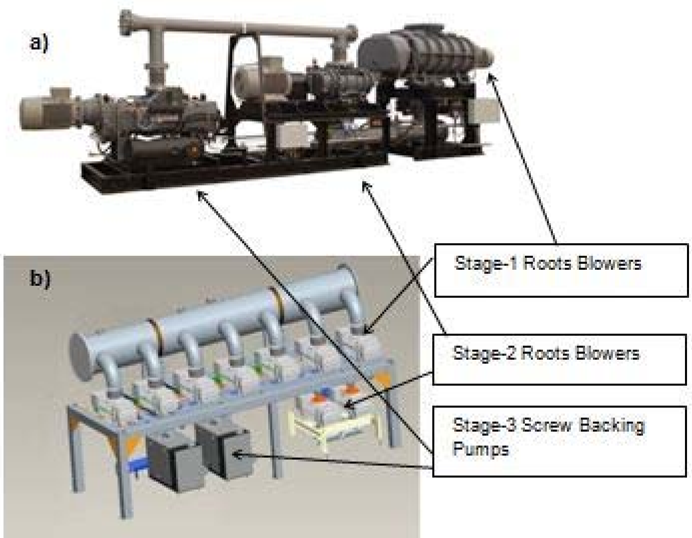

Figure 5: Detailed layout of two different types of pump skid: a) 3-stages skid (1-1-1 type); b) 3-stages skid (7-2-2 type)

Typical MVP frequency-current curves

One of the most attractive features of the MVP is the fact that every single pump is provided with a Variable Speed Drive (VSD). Indeed, by implementing the control of these drives through the general VD process-automation system, a perfectly tuned pump mechanical and electrical management can be attained with the intention of simultaneously achieving the shortest possible pump-down time and keeping the pumps all the time working in safe conditions.
In order to have a better understanding of the way the pumps are controlled in terms of frequency and current absorptions, the pertinent curves attained in some plants during vacuum treatments are reported in Figure 6 and 7.

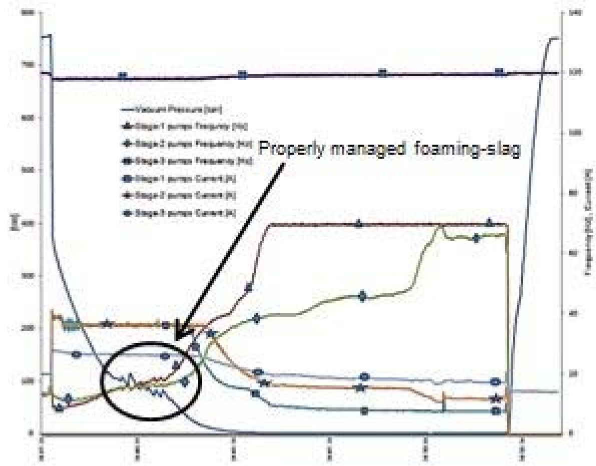

Figure 6: Typical frequency-current curves during a VD treatment in BVK plant (1 skid, 6-2-2 type)

From the trends illustrated in the above figure, it can be noticed that during the pump-down the pump speed is limited by the maximum allowed current absorption: these current absorption thresholds vary according to different frequency ranges and thanks to the on-field tuning their optimal values have been set. Differently from SVP pumps, during the pump-down thanks to the intervention of VFD the pumps consumed energy is minimized and continuously adapted to the instantaneous process requirement; on the contrary for SVP systems the steam consumption is not dynamically regulated (except some small steam-flow regulation applied in function of condenser water temperature) but, instead, kept constant at the foreseen static value throughout the treatment. Proceeding with the analysis of Figure 6, at around 100 torr of vacuum pressure foaming-slag phenomena occurred and were properly controlled thanks to the prompt intervention of the dedicated nitrogen injection line, which is capable of sufficiently raising the degassing tank pressure when the tank pressure is in the range of 20-200 torr.

Attained pump-down performances

In Table 1, the performance achieved for recently commissioned Danieli VD plants provided with MVP are reported. Considering the final vacuum attained during cold-tests in Gerdau Special Steel North America plant, the attained value was slightly bigger compared to the one achieved in ABS-Italy plant (0,3 torr) since at the time the cold test was carried out during the equipment commissioning phase the leakages were slightly higher than the successively achieved <20kg/h. It is to be remarked that, for BVK project, the relative pump-down time contractual guarantee figure was 5.0 min while the achieved figure was 4.0 min. Such good performances were accomplished thanks to both a very accurate overall VD-VOD equipment mechanical installation that allowed reaching very low level of leakages (<4kg/h) and to a finely tuned pumps management in terms of frequency and current-absorption automatic control. The very small equipment overall leakages permitted at the same time the achievement of very low final vacuum pressure during normal production. With the argon bottom-stirring high enough, the vacuum level reached during the performance treatments ranged between 0.4torr and 0.8torr.

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Plant	Heat Size	Leak Rate	Pump-down time empty tank	Pump-down time treatment	Final Vacuum Cold-test
	t	kg/h	min	min	torr
BVK Russia (VD/VOD)	20	< 4	4,0	5-8*	0,2
ABS Sisak (VD)	65	< 15	4,8	5-8*	0,3
ABS Italy (VD)	100	< 20	5,0	5-8*	0,3
Gerdau Spec. Steel North Am. (VD)	116	< 20	4,9	5-8*	0,4

Table 1: Summary of results attained for recently commissioned Danieli MVP-VD equipment

In the following Figure 8 a series of 5 consecutive pump-down curves (carried out at BVK-Russia plant) from 1 atm down to 1 torr (starting with a pre-evacuated textile filter) towards empty VD-tank are displayed.

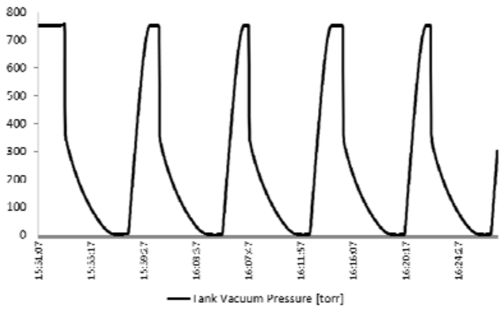

Figure 8: Series of 5 consecutive pump-down curves with empty tank in BVK plant.

As previously remarked, the average attained pump-down time was 4.0 min and the performance curves during the consecutive tests were practically identical.
In Figure 10 the pump-down curve performed during a VD-treatment is overlapped with a pump-down curve achieved with the empty degassing tank: the influence of foaming-slag phenomena on such a curve is noticeable. However, despite the foaming-slag events, it has to be pointed out that the time to reach 1 torr was only slightly increased (of around 2 min) thanks to a prompt and efficient antifoaming nitrogen-injection system into the degassing tank.

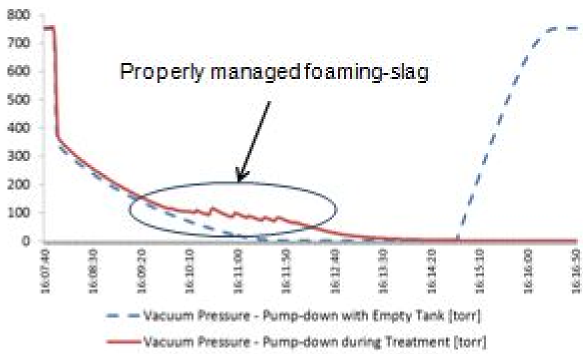

Figure 10: Comparison between VD treatment and empty-tank pump-down curves

Attained VD-VOD metallurgical performances

The simultaneous presence of very low vacuum level and very small VD equipment leakages together with suitable stirring management allowed achieving a remarkable and fast hydrogen removal in short time. The pertinent performances reached in several plants are reported in detail in Table 2 and Figure 11.

		ABS Sisak	ABS Italy	Gerdau North A.
Number of heats	#	25	30	10
Heat size	t	65	100	116
Pump-down time	min	6	7	7
Deep Vacuum time(<1torr)	min	15	20	13
H start	ppm	6.3	6.1	4.8
H end	ppm	1.0	1.0	1.5
H removal coefficient	m/min	0.26	0.25	0.35
N start	ppm	90	83	90
N end	ppm	55	49	58
N removal	%	38	41	36

Table 2: Summary of metallurgical results attained during Performance Test in 3 of the last installed Danieli MVP-VD equipments.

The results attained in all the MVP-VD commissioned plants, specifically in ABS Sisak and Gerdau Special Steel North America plants, were better than the relative contractual figures (detailed results are displayed in Figure 11) and this success was possible thanks to a properly designed and customized equipment engineering and a state-of-the-art process technology which came out from the accumulated field experiences.

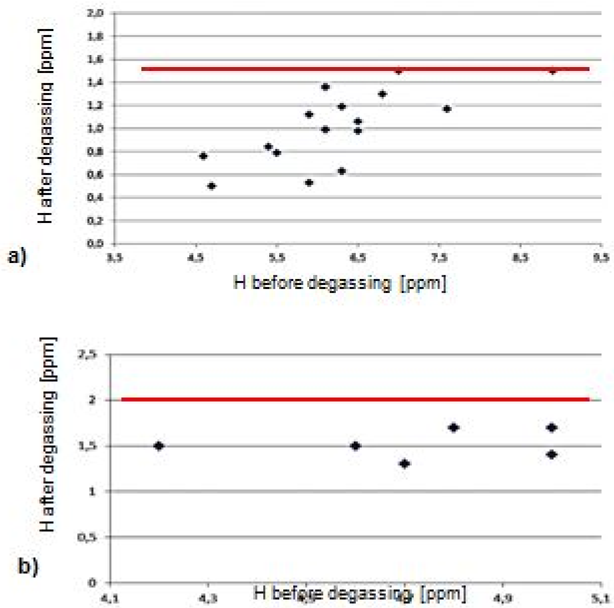

Figure 11: H content achieved after degassing, in function of the initial content, during the Performance Guarantee Test in: a) ABS-Sisak, target H≤1.5ppm; b) Gerdau Sp. Steel North Am., target H≤2.0ppm

The realization of an efficient, reliable, repeatable and properly performing VOD process provided with MVP, necessitates a more dedicated and developed pumps control. In particular, the whole VOD equipment must deal with the following additional issues in comparison to a VD one:

a. Exhaust process-gas thermal load towards the pumps is much higher since its temperature is higher and additionally a long part of the process (oxygen blowing) is carried out at quite high pressures (20-200 torr) where the sucked mass flow is considerably higher;
b. The pumps working cycle is more demanding since for every single VOD treatment they are working for a period that can vary from 20 to 50 min in a pressure range (200-20torr) where the power absorbed by the pumps is higher. The total pumps running time per heat is 2 to 4 times longer than for a VD process;
c. Throughout the oxygen blowing phase a dynamic automatic vacuum-pressure control is required in order to get the best metallurgical results.

"Item a" has been successfully addressed by a proper gas-cooler and textile filter installation provided with a dedicated automatic inlet temperature monitoring and controlling system. The issue related to pumps additional thermal load reported in "item b" has been figured out by adopting a more powerful inter-stage cooling system. Regarding "item c", a smooth dynamic automatic vacuum-pressure control has been achieved in all the four VOD plants started up and commissioned so far (Kama Stal, Kulebaky, Mechel, BVK) thanks to the variable frequency drive (VFD) with which each pump was provided and, when the metallurgical dynamical model was installed, thanks to the implementation of the automation-level 2 dynamic process-control. Typical pressure regulation curves attained during the VOD performance guarantee-tests in Kama Stal and BVK plants are reported in Figure 12.

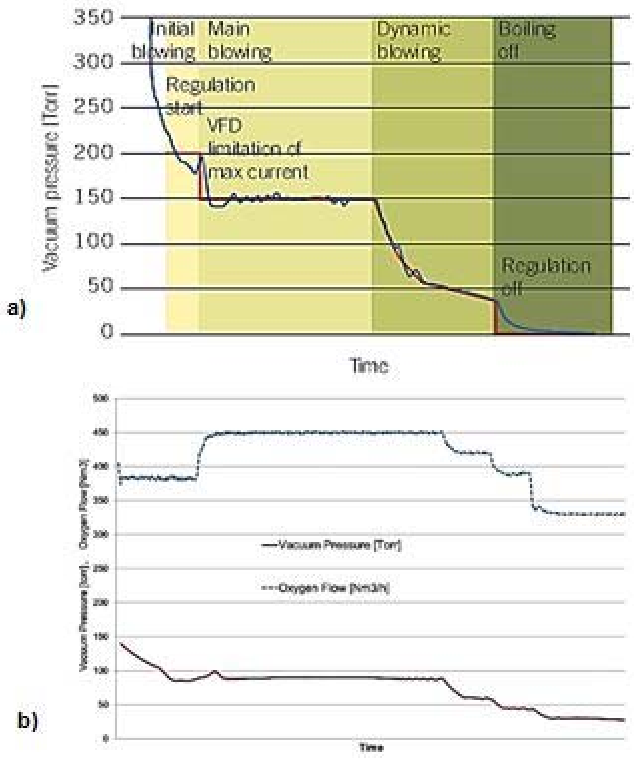

Figure 12: VOD automatic dynamic pressure regulation performed in: a) Kama Stal plant; b) BVK plant: the trend is focused on the oxygen-blowing phase (5 steps)

The above mentioned optimized overall installations (and consequently process) management allowed reaching better values compared to the contractual metallurgical guaranteed figures: in Figure 13 the successful results obtained during the start-up and performance tests period of two plants are reported with regards to the final carbon achieved after the whole VOD process.

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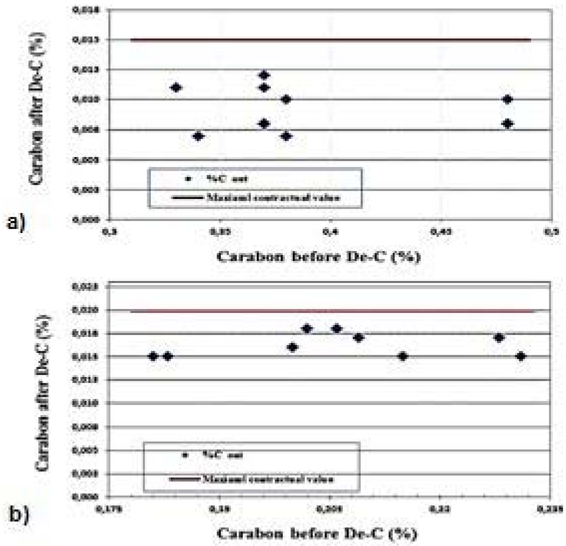

Figure 13: VOD Final Carbon Performance Test results: a) at Ruspolymet Group plant (contractual figure C≤0,015%); b) at ChMP plant (contractual figure C≤0,020%)

MVP electrical energy consumption

For VD treatment consisting of 7 min of pump-down time and 15 min of deep vacuum time (< 1torr), the average specific electrical energy consumption turned out to be 0.96 kWh/t. If additionally considering the energy spent by the MVP between one vacuum treatment and the following one, the average total electrical energy consumed for a heat treatment was around 1,30-1,40 kWh/t, with an average pump-off time of 15-20 min during a production sequence. Such results are further corroborating one of the most attractive advantages of MVP if compared to SVP, which is the overall yearly running-costs saving of around 70-90% [2, 3].
In Figure 14, vacuum-pressure in the degassing tank and in the bag filter together with MVP electrical-energy consumption (total kWh) trends are reported in function of pump-on and pump-off time.

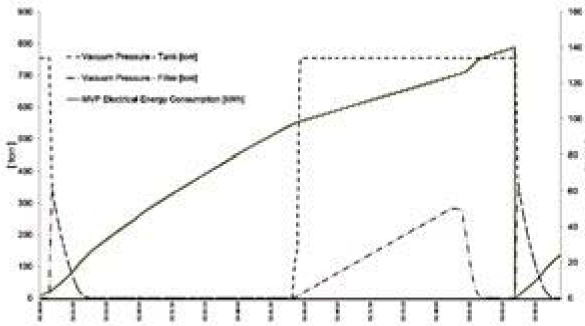

Figure 14: Typical MVP electrical energy consumption trend for 100t VD treatment

Concerning ABS-Italy 100t-VD equipment, for instance, typical recorded values of the absorbed power during the different phases displayed in Figure 14 were the following:

- Average power during ramping-up of stage-3 pumps from 0 to 60 Hz = 220 kW
- Average power during filter cleaning = 110 kW
- Average power during filter pre-evacuation from around 300 torr = 255 kW
- Average power while waiting for the heat to arrive on VD station, once pre-evacuated the filter = 127 kW
- Average power during treatment pump-down = 313 kW

- Average power during deep vacuum time (< 1 torr) = 216 kW

Throughout a production sequence, also between one heat treatment and the following one, the backing pumps are kept running to their maximum frequency in order to maintain their body warm enough to achieve their best performance and with the intention to keep the filter under vacuum and consequently to minimize the preparation and pump-down time of the following heat treatment. It is to be highlighted that the overall time required to be ready to start a heat vacuum treatment at the VD station, when all the pumps are switched off, for a MVP system is around 10 min: if compared to a steam boiler, the mentioned time required by MVP systems (and therefore the consumed energy) is much smaller. This is highlighting the advantageous feature of the MVP-based degassing systems that is the push-button availability. Regarding the above reported power absorbed (and relative energy consumed) while waiting for the next heat to arrive at the VD station, its value is zero when the equipment productivity is high (there is no waiting time).

Running-costs considerable saving by replacing SVP with MVP-based degassing system.
As already pointed out before, it is first of all interesting to note that the overall electrical energy consumption of a degassing system provided with MVP (ranging between 1.20-1.40 kWh/t including the auxiliaries) is smaller than the one of a degassing system provided with WRP-SVP (ranging between 1.40-1.60 kWh/t auxiliaries included). However, this is not the only consideration to be pointed out regarding the overall running costs comparison between the two degassing systems.
Proceeding with the running-costs comparison analysis, the following remarks have to be highlighted:

- Steam consumption: no steam is consumed for MVP systems while for SVP-WRP systems a lot of steam is consumed. Its cost figure depends on the type of a plant where the VD-VOD equipment is installed: if it is a part of an integrated steel plant, then the cost of steam will be lower compared to an electric steel-making plant since in integrated plants steam is already available (generated by BF and BOF equipments) and needs only to be kept sufficiently isolated and overheated in order not to have condensation phenomena during its use and consequent SVP's steam nozzles premature wearing. Further attention should be paid to push-button availability of MVP systems since this availability is not feasible at all for WRP-SVP systems: in fact while, as mentioned before, it takes maximum 10 min for a MVP–based degassing system to be ready for a treatment starting from a fully switched off status of the pumps, for SVP systems it takes much longer. Indeed, in order not to lose too much time for starting up the steam boiler, the boiler must be kept running at low fire in between the vacuum heats (even if they're not part of the same production sequence and there is a quite long waiting time between the two) and must be brought to full power some minutes before the maximum steam flow is requested for quick pump-down at the very beginning of each VD treatment. It goes without saying that during this waiting periods, steam is continuously consumed and therefore all the linked running-costs are growing minute by minute: this is an additional drawback of the SVP-based degassing systems;
- CO2-emission rights: the cost connected to this point does not exist for MVP degassing systems, while for SVP systems it is around 20 euro/t of emitted CO2 per year. However the exact amount of such "sanctions" depends on the Country where the equipment is installed; it is anyhow renowned that with the passing of years environmental consciousness is becoming more and more important all around the world and therefore this aspect will count more and more in the future;
- Contact water: it is used only for WRP-SVP degassing systems. Since the steam condenser contact water is coming into contact with a process gas containing dust and large amounts of CO, the running-cost of the whole contact water system includes the energy consumptions of water-circulation pumps, cooling

tower fans, sludge pumps, fans for forced ventilation of hot-well ,CO scrubbers and make-up water;

- Non-contact water: it is used only for MVP. Its aim on one side is to cool down the motors, bearings and casings of the pumps and on the other side to cool down the process gas by means of interstage heat exchangers. However, the total needed amount of such water and the heat developed by the pumps are lower if compared to SVP systems. For this reason such water can be kept in pressure closed circuit and can be handled with a simple secondary cooling system: the running-costs generated by this system are governed by small circulation pumps and cooling devices;
- Nitrogen: it is not used for SVP systems while it is used for MVP systems with different scopes: dust removing from filter-bags, filter repressurization and pumps purging;
- Gear box oil: its consumption (and relative cost) is related only to MVP and, however, is negligible;
- Maintenance: overall equipment maintenance costs are in favor of MVP degassing systems (relative savings range 5-10% in comparison to SVP 4). In fact, the only MVP maintenance activity required concerns the filter bags replacement while for a standard designed SVP system the permanent supervision of steam boiler and the monthly and yearly steam ejectors/condensers/hot well cleaning have to be taken into account;
- Dust disposal: MVP-based degassing systems are producing only dry dust (separated at cyclone and at filter bags) while SVP produces just a small amount of dry dust and a considerable amount of sludge: the cost for disposing the latter is much higher if compared to the cost of disposing the former. In fact the sludge water needs a long separation time by floating and the concentrated sludge would require an energy and time consuming drying before any valorization.

Drawing conclusions over the exact running-costs savings (by swapping from a WRP-SVP to a MVP degassing system) based on what has been explained in detail here above is not easy since all these running-costs depend on the geographical and political area where the considered plant is located and furthermore they depend on the type of a project considered (either a revamping of an old VD-VOD equipment or the introduction of a new equipment in an existing integrated or electric steel making plant or the installation of a completely new thorough steel making plant equipment). However, from the above detailed analysis it is clear that the overall running-costs balance is in favour of MVP systems, considering in particular the steam consumption, CO-emission, cooling water, maintenance and dust disposal voices.
The final decision whether to install a MVP or an SVP-based degassing system in a particular project will be made on a case by case basis, making an overall balance between capital and operative costs of the equipment to be installed. Regarding the VOD process, the operative-costs saving of MVP-VOD equipments are even higher compared to the VD case since the treatment cycle is 2 to 5 times longer with a resulting higher saving of steam and contact water.

4 CONCLUSION

The present article highlighted the successful response of Danieli to the market requirement of a running-costs saving and at the same time properly performing (from a metallurgy and productivity viewpoints) VD-VOD equipment: such response is embodied by the Vacuum Tank Degassing system provided with MVP that, thanks to an accurate mechanical and process engineering together with an on-site equipment and process fine tuning, allowed reaching the challenging required performance. When comparing the MVP-based degassing equipment with similar standard designed SVP-based equipment, one important advantage of the former system that must be highlighted is that the whole equipment availability is not strictly connected to other auxiliary equipments' constant and reliable performance (such as contact cooling water treatment plant and steam generation plant for SVP systems) and

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moreover it is not influenced by changes in environmental conditions. Taking also into account the extreme compactness and flexibility of such MVP degassing equipment together with its fast installation and commissioning phases, this system, besides its installation in completely new plants, can be either easily integrated in already existing plants without degassing station or profitably installed as a replacement/revamping of old SVP-degassing equipments, covering in this way the market request of higher demands on steel quality while keeping the costs low. In the end, with continuously increasing environmental consciousness and more restricting laws related to this matter, MVP-based degassing systems are gaining more and more importance and attraction since, differently from an SVP-based degassing system that includes a steam boiler, there are no emissions of CO2 into the atmosphere. Moreover dry-mechanical pumps are installed in a dedicated isolated and ventilated room that prevents the noise produced during their working from being spread around the plant, and this is an advantage in comparison with SVP-based degassing system: in reality also SVP systems can be efficiently isolated, but the insulation of the whole steam ejectors, condensers and suction line is more difficult.

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