Section 1: Vacuum Pumps in Steelmaking
Section 1 – Table of content

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Introduction

• Vacuum pump system provides the required pressure for degassing/decarburization purposes.

• Pressure required of 30-200 mbar in case of oxygen blowing and around 1 mbar for degassing/natural decarburization processes.

• Three types of vacuum pumps
  • Steam ejectors
  • Dry mechanical pumps
  • Water/Liquid ring pumps (only for gross vacuum)
Steam ejectors

- Based on impulse exchange (from steam and off-gas)

4-5 Stages necessary to compress the off-gas from deep vacuum to atmosphere

- Condensers are placed in between to reduce the amount of steam coming to next steam ejector

- Pressure regulation via by-pass
Driving force: steam (not electricity)
- Throttle of the steam (expansion) in a Laval-nozzle
- Mixing of steam and process gas (steam “pulls” the gas)
- Compression
Steam ejector – How it works?
Need of condensers
Steam ejectors – How it works?
Pressure regulation

Vacuum control measurement

- Process gas
- Steam condensate
- Process gas & non-condensates
- Offgas
- Steam condensate
- Process gas & non-condensates
- Steam condensate
- Process gas & non-condensates
- Offgas
- Steam condensate
- Process gas & non-condensates
- Offgas
- Steam condensate
- Process gas & non-condensates
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- Steam condensate
- Process gas & non-condensates
- Offgas
- Steam condensate
- Process gas & non-condensates
- Offgas
- Steam condensate
Steam ejector – How it works?
Simulation of pump-down
Dry mechanical pumps

- Based on compression of gas (reduction on suction chamber volume)

- 3-4 Stages necessary to compress the off-gas from deep vacuum to atmosphere

- Always screw pump stage discharging to atmosphere plus 2-3 stages of rotary blowers

- Inter-stage cooling in some applications

- Modular/skid solution (independent modules) or “customized” (the vacuum pump stages are interconnected not only on the suction line)
Dry mechanical pumps
Basics

• Screw pumps

• Rotary blowers
Dry mechanical pumps
Modular solution
Dry mechanical vacuum pumps
“Customized” solution - VAGL

Aerzen

Busch
Liquid/Water Ring pumps

- Based on compression of gas (reduction on suction chamber volume)

- Impeller creates a liquid ring sealing the off-gas, which is compressed

- Due to water, the minimum pressure which can be reached is limited (150-200 mbar at nominal load). New WRP design able to work down to 50 mbar.

- Used as last stage in steam ejectors (to reduce steam consumption) and in some facilities instead screw pumps (VOD)
<table>
<thead>
<tr>
<th>Steam ejectors</th>
<th>Dry mechanical pumps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam</td>
<td>Filtering system</td>
</tr>
<tr>
<td>Water treatment facilities</td>
<td>Off-gas cooling system (filter and pump limitations)</td>
</tr>
<tr>
<td>Filtering system (optional to reduce dust content in water)</td>
<td></td>
</tr>
</tbody>
</table>

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## Short comparison
### Some aspects to be considered

<table>
<thead>
<tr>
<th></th>
<th><strong>Steam ejectors</strong></th>
<th><strong>Dry mechanical pumps</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Investment</strong></td>
<td>- Base high but decrease with size. Auxiliaries to be considered</td>
<td>- Increase linearly with capacity and process</td>
</tr>
<tr>
<td><strong>Suction capacity</strong></td>
<td>- A bit oversized in design for deep vacuum</td>
<td>- Pump performance for deep vacuum is limited due to high investment</td>
</tr>
<tr>
<td></td>
<td>- Performance losses due to bad maintenance</td>
<td>- Awareness of customer of some performances (pump down with heat)</td>
</tr>
<tr>
<td><strong>Explosive mixtures</strong></td>
<td>- Not a problem as no ignition source is present</td>
<td>- Need of use of certified pumps for handling explosive mixtures</td>
</tr>
<tr>
<td>(oxygen blowing)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dust handling /</strong></td>
<td>- Wet removal (in condenser water).</td>
<td>- Dry dust removal</td>
</tr>
<tr>
<td><strong>Water treatment</strong></td>
<td>- Water treatment needed</td>
<td>- Machine cooling water high quality (as normal equipment)</td>
</tr>
<tr>
<td></td>
<td>- Filter/Cyclone reduces amount</td>
<td></td>
</tr>
<tr>
<td><strong>Pressure regulation</strong></td>
<td>- Bypass valve</td>
<td>- By-pass valve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Frequency regulation</td>
</tr>
</tbody>
</table>
Summary

- Which pump type to offer is a tailor-made solution
- Process and customer media availability gives 90% cases
- Mechanical pumps “trend” in market
VD Plants

- Vacuum tank degassing is one of the oldest degassing techniques in use in the steel industry for improving steel quality.
- A teeming ladle is placed in a vacuum tank, which is connected to a vacuum pump system.
- The ladle is equipped with porous plugs through which inert gas is injected into the melt in order to promote stirring.
- Metallurgical reactions: degassing, deoxidation, desulphurization as well as alloying, take place under vacuum conditions.
VD Plants

Metallurgical benefits

- Rapid reduction of hydrogen content typically from 6 to less than 1.5 ppm
- Removal rate of nitrogen up to 40% (depending on steel grade and initial level)
- Desulphurisation - slag-metal balance brought closer to equilibrium < 30 ppm
- VCD Vacuum Carbon Deoxidation - “inclusion-free” deoxidation by carbon
- Small tolerances of alloying elements
Twin VD layout
Preparation of melts for vacuum refining

**EAF Tapping**
- temperature control
- carryover slag control
- deoxidation
- alloying
- slag making additions

**Ladle Furnace**
- slag control (composition, volume, oxide reduction)
- steel composition control (alloying to final grade aims - except for elements with high oxygen affinity)
- deoxidation control and aluminium trimming
- temperature increase (to compensate losses in vacuum station)
### Process Route 1

EAF – LF – VD (20’) (Degassing) – CC

#### Sample Data

<table>
<thead>
<tr>
<th>No</th>
<th>Process Step</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Al</th>
<th>H ppm</th>
<th>Temp °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>EAF TAP</td>
<td>0.05</td>
<td>0.01</td>
<td>0.1</td>
<td>0.01</td>
<td>0.02</td>
<td>0.00</td>
<td>6</td>
<td>1620</td>
</tr>
<tr>
<td>2</td>
<td>LF END</td>
<td>0.6</td>
<td>0.25</td>
<td>0.75</td>
<td>0.01</td>
<td>0.007</td>
<td>0.02</td>
<td>7</td>
<td>1610</td>
</tr>
<tr>
<td>3</td>
<td>VD END</td>
<td>0.6</td>
<td>0.20</td>
<td>0.75</td>
<td>0.01</td>
<td>0.005</td>
<td>0.005</td>
<td>1.5</td>
<td>1560</td>
</tr>
</tbody>
</table>

**Steel Grade:** 1060 min  
Liquidus 1490 °C
Check Argon porous plugs performance!
Bad stirring worsens vacuum degassing!!
1 Sample

SAMPLE, EMF, T, Hydris

EMF control!

Al - deoxidation according to Al-Deoxidation Model!

Desulphurization slag according to slag model for LF addition!

Additions preparation!
1 Vacuum start

Vacuum Start

Vacuum Pump

Start treatment vacuum pump

Observe the melt surface through sight pot camera:

Slag **boil up** to ladle lip ⇒ **increase pressure** (open flooding valve)

**Boil stop** ⇒ close flooding valve, **continue pump down**
P < 10 mbar ⇒ lift Argon flow to 300 l/min, add all additions from hopper

Degassing Treatment time starts at P < 2 mbar

Degassing time = 20’
When the treatment is completed, then stop treatment.

The tank is flooded with ambient air to atmospheric pressure, filter is cleaned and flooded.
1 sample b

Wait the results of Sample, T, EMF
**Wire Injection**

- **Al wire** addition for final deoxidation
- **CaSi wire** for modification of non-metallic inclusions
The heat is treated with **soft argon bubbling**, the slag surface is not broken.
Ladle Lift for Casting
Metallurgical processes in VD

- Hydrogen removal
- Nitrogen removal
- Decarburization
- Desulphurization
- Evaporation under vacuum
- Stirring parameters
- Steel composition control
- Inclusion shape control
Hydrogen removal depends on time under vacuum

Strong stirring during deep vacuum favors removal but increases skull formation

Higher initial content will require longer time for the same final content

Dry additions required
Metallurgical processes in VD

Nitrogen removal

- Behavior of nitrogen removal is similar to hydrogen removal with important remarks

- Sulfur content and oxygen activity reduce/limit nitrogen removal (sulfur will be removed first)
Metallurgical processes in VD

Decarburization

- Carbon removal appears in almost every vacuum treatment as equilibrium is lower
- Non-oxidized steel promotes decarburization but it is not the case of VD treatment
- Small CO production possible
Stirring rate has direct influence on vacuum degassing process
Low stirring at pump down phase, increase at deep vacuum
High stirring rate favours degassing (splashes if low freeboard!!)

<table>
<thead>
<tr>
<th>Phase</th>
<th>Stirring rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degassing</td>
<td>3 – 8 Nl/(ton·min)</td>
</tr>
<tr>
<td>Self-decarburization (Boil-off)</td>
<td>2 – 4 Nl/(ton·min)</td>
</tr>
<tr>
<td>Quick Homogenisation</td>
<td>&gt; 3 Nl/(ton·min)</td>
</tr>
<tr>
<td>Strong desulphurization</td>
<td>&gt; 3 Nl/(ton·min)</td>
</tr>
<tr>
<td>Waiting, Final Stirring, trimming</td>
<td>0.5 Nl/(ton·min)</td>
</tr>
</tbody>
</table>
Factors ensuring proper plug performance

- A clear responsibility for permeability tests, cleaning and replacements done at the ladle service stands
- Start of purging immediately after ladle arrival to treatment station
- Use of the plugs on every heat (this is important if the steel plant has an alternative secondary treatment stations not equipped with bottom stirring)
- A guaranteed steel superheat above liquidus not lower than 40-50°C
- Regular tightness check of gas piping and gas connections on the ladle
# VD Plant Equipment

## Vacuum vessel – Failure / Malfunction / Maintenance

### Failure / malfunction

<table>
<thead>
<tr>
<th>Failure / malfunction</th>
<th>Reason</th>
<th>Countermeasures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum cannot be established</td>
<td>Leakage at the sealing ring</td>
<td>Clean the sealing flange or exchange the seal</td>
</tr>
<tr>
<td>Stirring system does not work</td>
<td>a) Damage to the hoses</td>
<td>a) Exchange the hoses</td>
</tr>
<tr>
<td></td>
<td>b) Damage to the quick couplings</td>
<td>b) Exchange the quick coupling</td>
</tr>
<tr>
<td></td>
<td>c) Porous plugs are stuck</td>
<td>c) See chapter 7.2, “Ladle stirring equipment”</td>
</tr>
<tr>
<td></td>
<td>d) Malfunction at the argon/nitrogen valve</td>
<td>d) See chapter 7.16, “Piping: Valves, Fittings, Hoses, Rack, Etc.”</td>
</tr>
</tbody>
</table>

*Keep clean! Check bolts Check refractory*
The Siemens VAI automatic gas coupling system is a **quick, safe, reliable and maintenance friendly connection** device for the stirring gas supply to the steel ladle.

The system **actuates immediately and automatically** by placing the ladle on the ladle station or on the transfer car.

It safe guards the supply of the stirring gas to the ladle automatically **without the need for personnel** to connect hoses to the supply source.
Automatic gas coupling system
Operation principles

- Tight control of ladle stirring applications during the whole production process.

- Ensures the automatic connection without the need of personnel.

- Actuation of the system is done by placing the ladle on the respective stirring position.
Automatic gas coupling system
System configuration 1/4

- Two main parts:
  - Upper/female part which is mounted on the respective ladle
  - Lower/male part which is located on the respective stirring stations.

- The compact lower section is equipped with spring-loaded pins, which allow flexibility in the X-, Y- and Z-axis planes.

- This principle enables the unit to compensate for a possible misaligned ladle position.

- The lower section is connected to the gas supply lines by a flexible metal hose.
Automatic gas coupling system
System configuration 2/4

Multiple gas coupling

- Depending on the requested flow rate or number of porous plugs respectively the gas coupling itself consists either of one, two or three gas couplings.

  - The design of multiple gas couplings is an arrangement of two or three single gas couplings joined together with a flange.

  - The well proven design for the single gas coupling is therefore duplicated to allow higher gas flows.
Automatic gas coupling system
System configuration 3/4

AGC - 25
≤ 2,500 N l/min*

AGC - 50
≤ 5,000 N l/min*

AGC - 75
≤ 7,500 N l/min*

*max. flow rate
Automatic gas coupling system
System configuration 4/4

Typical layout

- Main operator panel (HMI) via Fieldbus to Control System (PLC) via Fieldbus
- Control System (PLC) sends Ar and N2 to Valve station
- Valve station sends signals to Ladle stirring stand, Ladle tilting stand, and Ladle transfer car via ‘and/or’ connections
- Local operator panel connects to Valve station
- Fieldbus and/or ‘and/or’ connections between devices

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SIMETAL Automatic gas coupling system
Components male part

- Sealing head
- Connecting pipe
- Base frame
- Cylinder screw
- Straight male stud fitting
- Spring protective cover
- Inner cover
- Key
- Pressure spring
- Distance ring
- Mounting Frame
- Disc
- Spherical washer & hex. nut
SIMETAL Automatic gas coupling system
Components female part

Upper / female part

- Plate
- Hex. head screw
- Straight male stud fitting
- Washer
- Nut
- Sealing cone
- Cone
- Counter flange
- Hex. head screw
- Washer
- Sealing Ring
Automatic gas coupling system
Self-uprighting mechanism

NO friction during uprighting due to simple tilting mechanism

Not actuated

actuated
Nitrided sealing head ensures the round shape of the base material which is not the case if e.g. a chromium coating is used. Additionally this type of coating is harder than e.g. chromium.
Automatic gas coupling system
Deflection

High deflection in horizontal and vertical direction compared to size.
Automatic gas coupling system
Gas control system variants

Manual at valve station

Semi-automated from control room with multi-level control panel

Automated stand alone system from control room with HMI based touch panel

Automated and fully integrated in automation system (L1 or L2)

For every valve stand and its application the optimal type of control system can be applied. Due to this flexibility different types of control systems can be integrated in one melt shop.
Automatic gas coupling system
Valve station variants

1 valve station per stirring position recommended

No. of lines generally depending on no. of porous plugs

Type of control system independent from type of valve station

Following options are possible for bypass: manual or automatic plus flow rate measurement

Another option is that either one or two different types of stirring gas can be purged
Automatic gas coupling system
Performance / Maintenance

**Performance**

AGC 25  Single line  up to 2,500 N l/min
AGC 50  Double line  up to 5,000 N l/min
AGC 75  Triple line  up to 7,500 N l/min

**Maintenance**

- Simple and sturdy design, good accessible and easy to disassemble
- No active moving parts
- Automatic gas coupling system allows adjustment of initial tension of the male part w/o change of installation situation
## Automatic gas coupling system

### Scope of supply and services

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
</table>
| **Coupling**                       | • Male part  
• Female part  
• Flexible hose  
• Mounting bracket |
| **Engineering for stirring positions** | • 3D engineering for all stirring positions  
• Interference check of all ladles in combination with all stirring and parking positions  
• Piping engineering (BD+BE+DE) |
| **Engineering for ladles**         | • 3D Engineering for all ladles.  
• Piping engineering (BD+BE+DE) |
| **Valve stand**                    | • 3D engineering for valve stand  
• Valve stand supply  
• Basic data for interconnection piping |
| **Interconnecting piping**         | • Basic engineering  
• Detail engineering  
• Supply of piping material |
| **Site investigation**             | • 3D scan of all ladle stirring and parking positions  
• 3D scan of ladles  
• 3D as built engineering (before installation of coupling) |
Automatic gas coupling system
Gas control system

Gas control system layout:

The Siemens gas control system consists of two main units:

The main operator pulpit (e.g. HMI) located in the control room regulating all parameters concerning the gas stirring process, and the valve station with a PLC and flow meters regulating the gas flow.

Optionally, the valve stand can be designed for using different kinds of stirring gas.
Automatic gas coupling system

Benefits

- Safety for operation personnel – no activities in dangerous areas
- Quick and safe connection – simply placing the ladle onto stirring station
- High flexibility – compensates for possible misaligned ladle positions
- Low maintenance – simple and sturdy design with good access
- Compact and solid construction – especially important in case of limited space
- Reliable operation – no active moving parts
- High temperature resistance – enables high temperature applications, e.g. in VOD plants
- Low capital and operational costs
Automatic gas coupling system

References

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Ispat Sidex Romania 2004
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Maanshan China 2006
Alchevsk Ukraine 2006
DMK Ukraine 2006
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ZPPS China 2007
Alchevsk Ukraine 2007
DMKD Ukraine 2007
AMK-Melt Ukraine 2008
Ahmsa Mexico 2008
Maanshan China 2008
Georgsmarienhütte Germany 2008
Outokumpu Finland 2008
Bhilai India 2010
ArcelorMittal Genk 2013
Rio Tinto Fer Titane 2013
TMK Ipsco 2014
Arkansas Steel Associates 2014

More than 20 SIMETAL Automatic gas coupling system delivered worldwide
Automatic gas coupling system
Contacts

Rob Strain
Product Manager
Primetals Technologies USA LLC
501 Technology Drive
Canonsburg, PA 15317
Phone: (724) 514-8297
Mobile: (724) 263-3846
E-mail: rob.strain@primetals.com