catalysts europe

EUROPEAN CATALYST MANUFACTURERS ASSOCIATION

Catalyst handling best practice guide

Catalysts Europe
Rue Belliard 40, Bte 15, 1040 Brussels Belgium
Tel. +32 490 30 46 07 dki@cefic.be **www.cefic.org**

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Catalysts Europe, the European Catalyst Manufacturers Association, is a sector group of the European Chemical Industry Council (Cefic) and represents the leading catalyst producers in Europe. Catalysts Europe is a non-profit organisation established in 1983 and dedicated to promoting the safe use and benefits of catalysts to society.

Catalysts play a vital role in everyday life by making many products possible, improving process efficiency, reducing energy consumption and reducing emissions and waste.

One of Catalyst Europe's major goals is to promote the safe use of catalysts over the whole life cycle including manufacture, installation in industrial reactor systems and spent catalyst management including regeneration, recovery and disposal. Spent catalysts have been recycled for many years and have made a significant contribution to reducing waste and the circular economy. Dedicated catalyst regeneration companies are members of Catalysts Europe.

Acknowledgements

This document was put together with the support of a number of catalyst handling companies including BUCHEN-ICS, Cat Tech, Mourik, Petroval, Technivac and Unicat. Catalyst handling is a specialised area and their support was invaluable.

Update

This document has been updated to incorporate advances in technology both for the catalysts themselves and the equipment used to handle them, but also to highlight the risks related to catalyst handling and to emphasise precautions that must be taken, notably in light of fatal accidents that have arisen during catalyst handling operations.

Current version – July 2026

Disclaimer

The information contained in this document is intended for guidance only and whilst the information is provided in utmost good faith and has been based on the best information currently available, it is to be relied upon at the user's own risk. This information is not intended to replace case-by-case assessment done by a professional. No representations or warranties are made with regards to its completeness or accuracy, and no liability will be accepted by Catalysts Europe or any of its members for damages of any nature whatsoever resulting from the use of this information.

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1.0 Introduction

The goal of this document is to provide guidance on the handling of catalysts in the safest possible way for human health and the environment. Catalysts are used in a wide range of applications, and it is important that they are used in a safe way. Catalysts are made up of different chemicals with varying hazard profiles and safe use requirements, and this should be taken into consideration in their use.

This best practice guideline is focused on solid heterogeneous catalysts installed in industrial reactors. For a better definition, please see section on catalyst types. Generally, this best practice guideline is also applicable for the handling of raw powder catalyst materials. Liquid catalysts, which are not covered in this document, can consist of hazardous substances and the reader is advised to follow the recommended risk management measures described in the corresponding safety data sheet (SDS).

This guide is intended for users, handling companies and designers of catalyst systems. It covers **catalyst specific guidance** and is designed **to supplement general safety practices**. Catalyst handling often involves Confined Space Entry and working in hazardous chemical and refinery sites. This guidance **assumes compliance with all applicable local legislation, specific site regulation and safety schemes** such as the VCA (Dutch Safety, Health and Environment Checklist for Contractors).

This guide has two sections. The first part is a description of different aspects including the various techniques used in catalyst loading and unloading. The second part in annex 1 is a checklist of the items that should be considered during these operations.

2.0 What are catalysts?

A catalyst is a substance that increases the rate of a chemical reaction but is usually not consumed by the reaction. A catalyst is normally chemically unchanged at the end of the reaction. Many catalysts are complex mixtures of different chemicals.

There are two basic types of catalysis:

Homogeneous - The reactants and the catalyst are in the same phase, generally in solution. The catalyst is usually recovered from the final product stream by a process such as distillation. It is reused until the catalytic activity is no longer sufficient. Often the raw catalyst material is supplied as a powder and the catalyst needs to be dissolved in an appropriate solvent before the catalyst can be utilised.

Heterogeneous - The reactants (normally liquid or gaseous) and the catalyst (normally solid) are in different phases. The catalyst pellets may be spherical, cylindrical, or randomly shaped. Many catalysts used in heterogeneous processes are extremely complex. Normally they consist of a number of principal components on an inert support material such as aluminium oxide or silica. When these solid catalysts are handled, they may generate airborne dust and therefore may present a risk when inhaled.

Figure 1: An example of catalysts

Solid catalysts may be sensitive to attrition which occurs during transportation, conveying, and transfer. Attrition results in the formation of fines/dust. Since these easily airborne fines present a risk for exposure to personnel and to the environment, it is recommended to avoid the dispersion of the fines and to adopt solutions to limit, confine, collect, and recycle them. Catalyst coating technologies exist with a thin layer of chemical component that limits the attrition and thus fines emissions.

Catalysts gradually lose their catalytic activity, usually through structural changes, poisoning, overheating, or the deposition of extraneous material such as coke. A catalyst is “spent” when it no longer exhibits the necessary activity or specificity required by the user. Depending primarily upon the chemical and structural changes in the catalyst during use, the user may have a number of options for dealing with the spent catalyst, which include:

- Regeneration and reuse of the material.
- Recovery of some or all of the components in the material
- Disposal of the material

2.1 Hazardous properties of catalysts

Catalysts are mixtures containing different chemical compounds. Some of these substances may have hazardous properties either to human health or the environment. It is important to take note of the information on the label and in the SDS to identify the risks associated with each specific catalyst, taking note that the hazards of a fresh catalyst and of a spent catalyst are not necessarily the same since the chemical

composition or the physical state may have changed.

Many substances used in catalysts have hazardous properties that can be linked to adverse health effects. **Check the safety is in the safety datasheet (SDS)** that is available from catalyst manufacturers or suppliers. As well as information on the hazards, the SDS contains details for the handling, transport and risk management measures such as personal protective equipment (PPE).

Hazardous substances may be present as dust, vapour and gas and can enter the body by a number of routes with the most likely routes via inhalation and skin absorption.

Some substances in catalysts can cause severe adverse health effects, if the catalyst is not handled properly. As mentioned, spent catalysts may have different hazardous properties including due to residual substances, which are chemicals that remain on the catalyst from the processed streams such as hydrocarbons, or incidental substances that have been formed in the reaction process.

Residual substances - Chemicals that remain on the catalyst from the processed stream. Depending on the installation, this can include substances such as benzene, butadiene or ethylene oxide.
Incidental substances - Probably the most concerning are metal carbonyls. Substances such as nickel carbonyl and vanadium carbonyl are some of the most toxic substances encountered in industrial processes.

2.2 Self-heating catalysts

These are mixtures which in large quantities and after a prolonged duration (several hours or days) are liable to self-heat in contact with air and without an energy supply. This may include some fresh and spent catalysts. Fresh hydrotreating catalysts are, most of time, loaded in an oxide form that needs to be In-situ activated by turning inactive metals oxides into active metal sulfides. Ex-situ activated catalysts may also be directly proposed by catalyst manufacturers. This preactivated form is self-heating.

The self-heating property is mainly due to the potential re-oxidation of sulfur species (metal sulfides) in presence of oxygen. Re-oxidation of metal sulfides can be considered as heating starter. Oxygen exposure must be avoided and loading in reactors must be completed under nitrogen atmosphere. Appropriate packaging and labelling are also required.

To mitigate this drawback, preactivated catalysts can be preventability treated by proprietary technologies to reduce and suppress their reaction with oxygen. This option enables the loading of the active catalyst under air and the potential use of more standard packaging.

For the case of spent hydrotreating catalyst, coke and hydrocarbons present in the porosity also amplifies the self-heating potential due to their combustion - either partial or complete. Unloading also normally takes place under nitrogen to create an inert environment and appropriate packaging and labelling is also required. Wet dumping using water can also be used.

3.0 Basic aspects

3.1 Reactor entry

This is required in some places as described in later sections. This is a critical operation requiring suitable breathing and skin protection. Those entering the reactor must have appropriate training and certification.

3.2 Confined space operation

Many catalyst operations involve entry into confined space. Confined space safety and permit procedures must be followed for these operations.

3.3 Working in inert atmosphere/nitrogen

Many catalyst loading and unloading operations have to be carried out in inert atmosphere, normally under nitrogen such as with self-heating catalysts. Typically, this is carried out by feeding nitrogen up flow through the reactor during either loading or unloading. Detailed procedures for working in inert atmosphere/nitrogen should be strictly followed.

3.4 Reactor conditions

The reactor should be purged of the process liquids and gases as much as possible before catalyst handling operations should start. The temperature should also be suitable for the operations. This is often 40°C but ideally it is below the body temperature of 37°C to prevent heat stress for the operators. Temperature and atmosphere should be monitored while operations are ongoing.

3.5 Static electricity

Vacuum systems and hoses have a risk to generate enough static electricity to ignite combustible atmospheres. Equipment and procedures such as conductive hoses should be used to prevent this.

3.6 Ancillary operations

Catalyst loading and unloading normally involves working at height and with forklifts and cranes. Suitable procedures and training should be in place to ensure safe operation.

3.7 Packaging

This includes big bags (FIBC), drums and forklift movable 1 – 2m³ bins. The packaging should be UN approved packaging suitable for the catalyst or spent catalyst. Minimizing the changeover of bags and drums can also reduce exposure.

4.0 Catalyst reactors

4.1 Fixed bed reactor

This is the most common type and is typically a cylindrical vessel filled with catalyst pellets with the gas or liquid reactants flowing down-flow through the bed and being converted into products. The reactor may have more than one catalyst in layers and inert material to support the catalyst and improve flow and distribution of the process gas or liquid. Ceramic balls are normally used as they are strong, can withstand high temperature and pressure, do not absorb liquid or gases and are resistant to chemical attacks including acid, alkali and organic solvents.

The reactor may have multiple configurations including one large bed or several beds in series. Reactors may have openings or internal transfer tubes to allow the catalyst to flow by gravity from the top of bed to the bottom bed during loading and unloading. Reactors in some cases have dump nozzles to allow catalyst emptying by gravity. Multiple bed reactors can have side manways to allow easy access into each bed or have internal catalyst support grids and trays with removable sections that can be removed to allow access to the next bed.

Maneuvering these grids and trays might be difficult depending on the design and potential seizing or jamming. Additionally, these operations are done under air or nitrogen atmosphere with associated risks. Moving ang lifting heavy material needs to be considered.

Ideally, catalyst handling is taken into account in the design of the reactor to ensure exposure to catalysts to be minimized during loading and unloading.

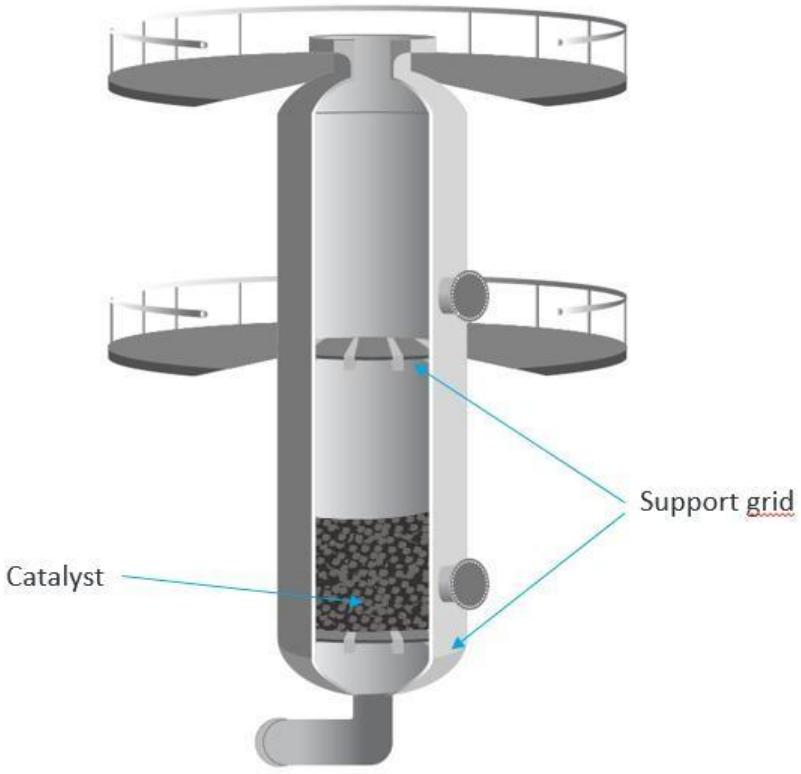

Figure 2: Example of a fixed two bed multiple catalyst reactor.

4.2 Tubular reactor/reformer

This consists of a series of tubes containing the catalyst. This is normally used where the process has to be carried out at high temperature where hot gases are on the outside of the tubes. Tubular reactors are also used where the process is highly exothermic and coolant is on the outside of the tube and where it is difficult to obtain and maintain the temperatures if a single bed was utilised. This type of reactor presents challenges for loading and unloading as the catalyst has to be put in and removed from these narrow diameter tubes without damaging the catalyst. Tubular reactors can have fixed or removable top and bottom domes or covers to access the tubes and install or remove the catalyst.

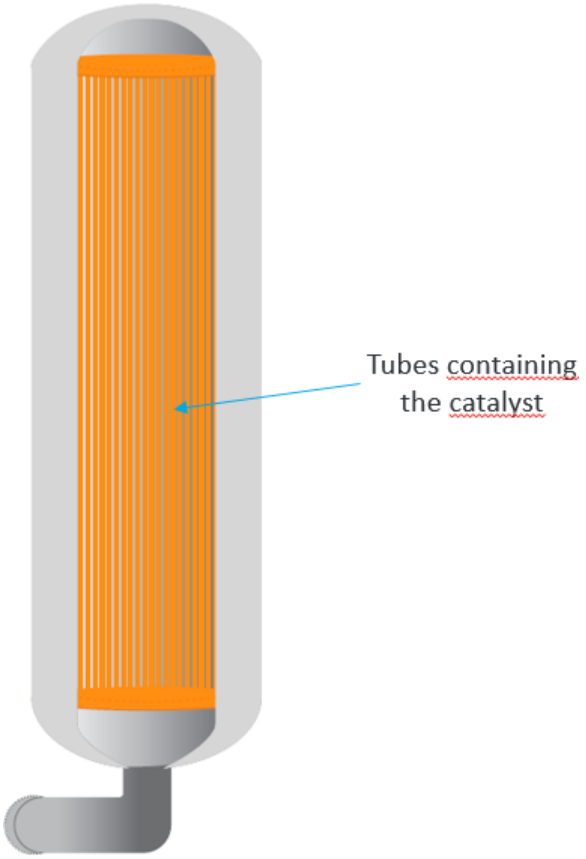

Figure 3: Example of tubular reactor.

4.3 Fluidised bed reactor

A fluidized bed reactor suspends small catalyst particles by the upward motion of the fluid to be reacted. The fluid is typically a gas with a flow rate high enough to mix the particles without carrying them out of the reactor. Fluidized bed reactors are typically multiple vessel units whereby under normal operation, the catalyst will migrate between vessels. This allows the catalyst to be moved through the vessel and into regeneration sections that will regenerate the catalyst and return it to the top of the reactor. A common fluid bed reactor is for Fluid Catalytic Cracking (FCC) used to crack heavy hydrocarbon feedstocks.

5.0 Catalyst handling hierarchy

Figure 4 gives an overview of the preferred options in the handling of catalysts. The choice will depend on the particulars of the installation and the equipment available.

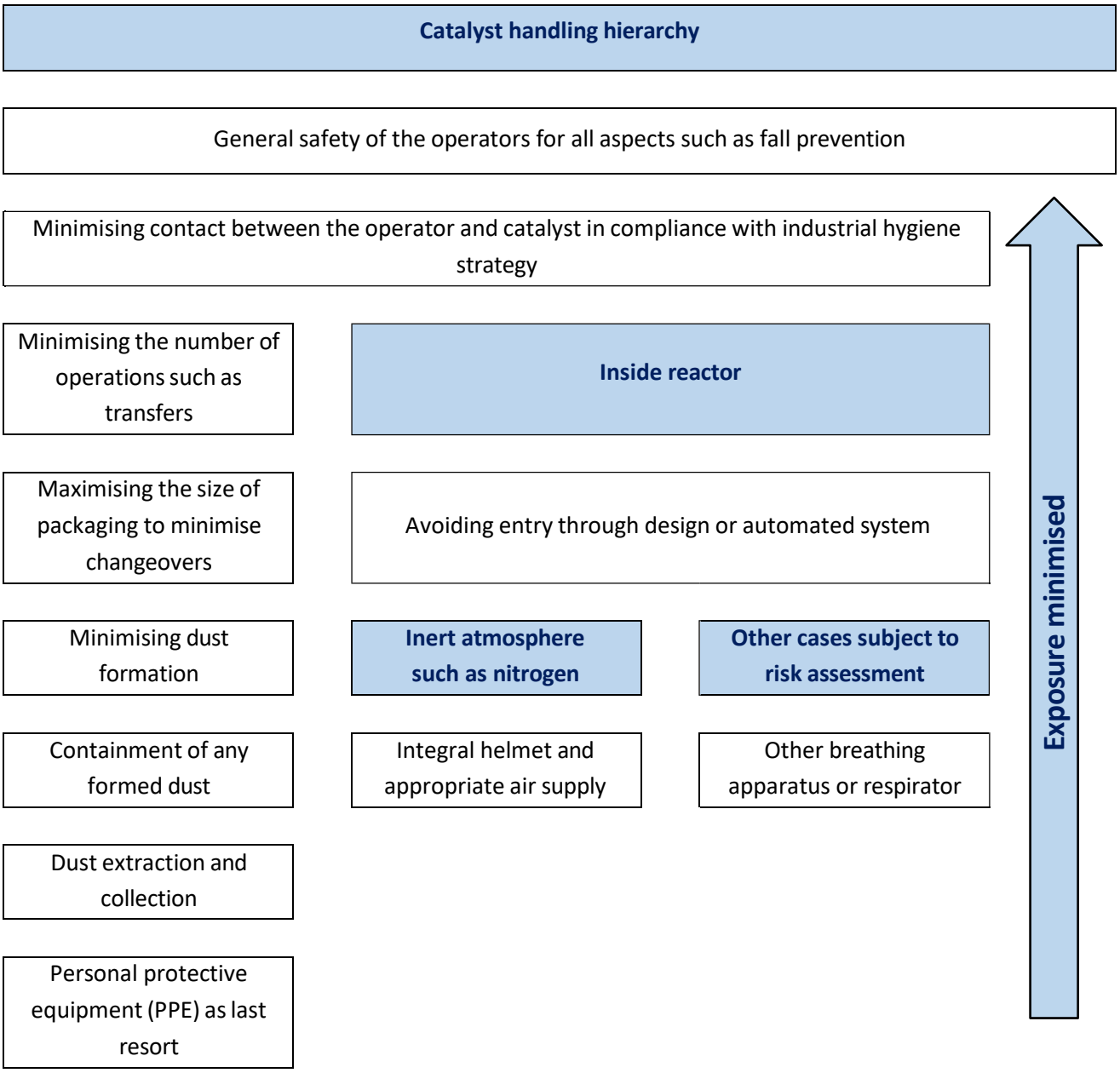

Figure 4: Catalyst handling hierarchy.

6.0 Reactor entry

As described in the catalyst loading hierarchy, avoidance of reactor entry is the preferred option. If reactor entry is required, particularly in the case of inert/nitrogen atmosphere or other potentially hazardous residual or incidental substances, an appropriate breathing apparatus such as an integral helmet and appropriate air supply is normally required. In some cases, other breathing apparatus or respirator is sufficient as long as a full risk assessment for reactor entry and confined space operation has been undertaken.

Reactor entry is a high risk operation and strict procedures are required including CE approved specialised equipment, supervision and training.

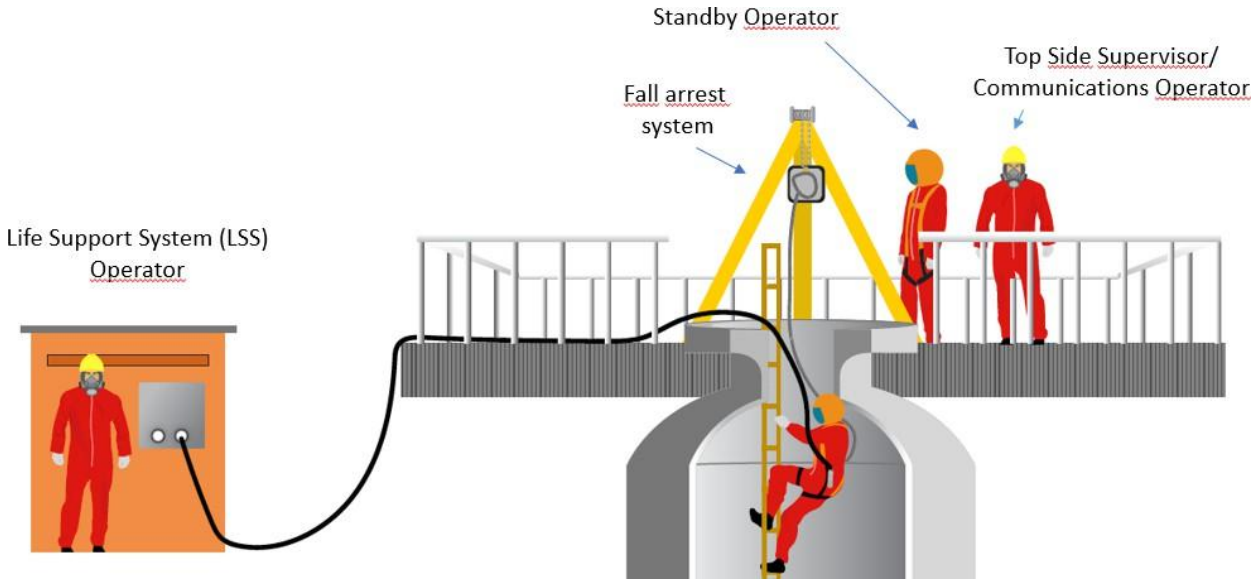

Figure 5: Example of life support system (LSS) organisation for inert entry on the top of a reactor.

Figure 6: Operator with integral helmet and full breathing apparatus. The picture on the right shows the top of a reactor with fall arrest tripod.

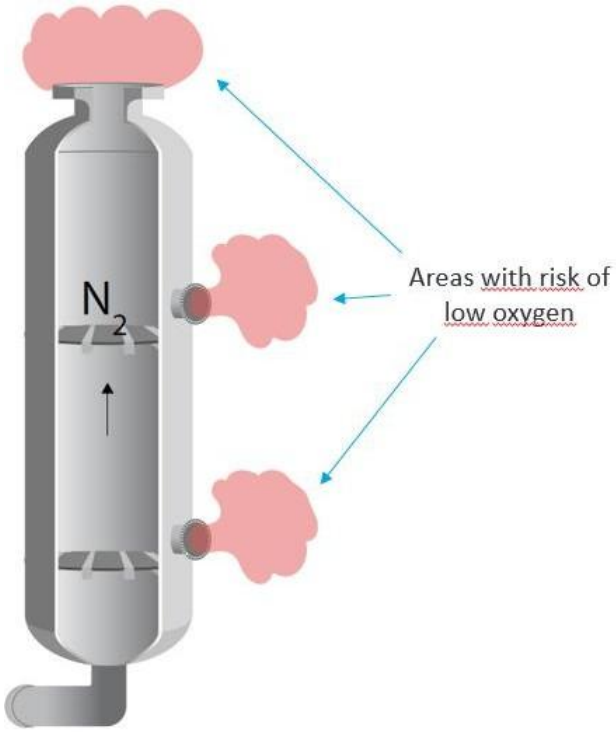

Figure 7: Risks areas during work under inert/nitrogen atmospheres.

Figure 8: Working in catalyst reactor with life support system.

7.0 Loading & unloading operations

This encompasses a wide range of operations including:

7.1 Preparation for loading or pre-bagging

This normally consists of transferring the catalyst from the original packaging into an intermediate hopper.

7.2 Loading into or unloading from the reactor

This is for the new catalyst or emptying the spent catalyst from the reactor.

7.3 Screening / Skimming

Most of the time the full inventory of spent material is unloaded and screening is performed ex situ.
Sometimes removing a top layer or all of the catalyst from a reactor can be required due to plugging, causing pressure drop and flow problems. Sieving is used to remove undersize material and then the catalyst is returned to the reactor. This may be required due to blocking of the top of the reactor causing pressure drop and flow problems. Sieving is also used to remove support material such as ceramic balls that can be used as support in catalyst beds.

7.4 Spent catalyst management

This includes putting the spent catalyst into suitable packaging / labelling for regeneration, recovery or disposal.

7.5 Waste management

This includes managing the empty packaging, used protective suits and other personal protective equipment and collected dust or spills.
In case of wet unloading, large quantities of contaminated water should be treated before disposal.

7.6 Ancillary operations

This includes forklift, crane and temporary scaffolding.

7.7 Preparation for loading

Care needs to be taken to avoid foreign materials such as drum liner, straps and ties from entering the reactor. Prior to loading, the reactor, support grids and ancillary equipment should be inspected. The reactor should be clean and dry.
Ceramic seals must be in good condition and placed at the right location. Ceramic seals may be hazardous for repeated exposure. Consult the manufacturer's recommendations.

8.0 Loading operations

The key issue is normally how to transfer the catalyst from the packaging in which it arrives on site into reactor. The approach can vary from directly discharging the catalyst from the packaging at ground level and transferring to the top of the reactor to transporting the packaging to the top of the reactor for filling by gravity. The following includes illustrations of the different loading operation. Inside the reactor, the catalyst is normally distributed by either dense loading or sock loading as described in sections 8.4 and 8.5.

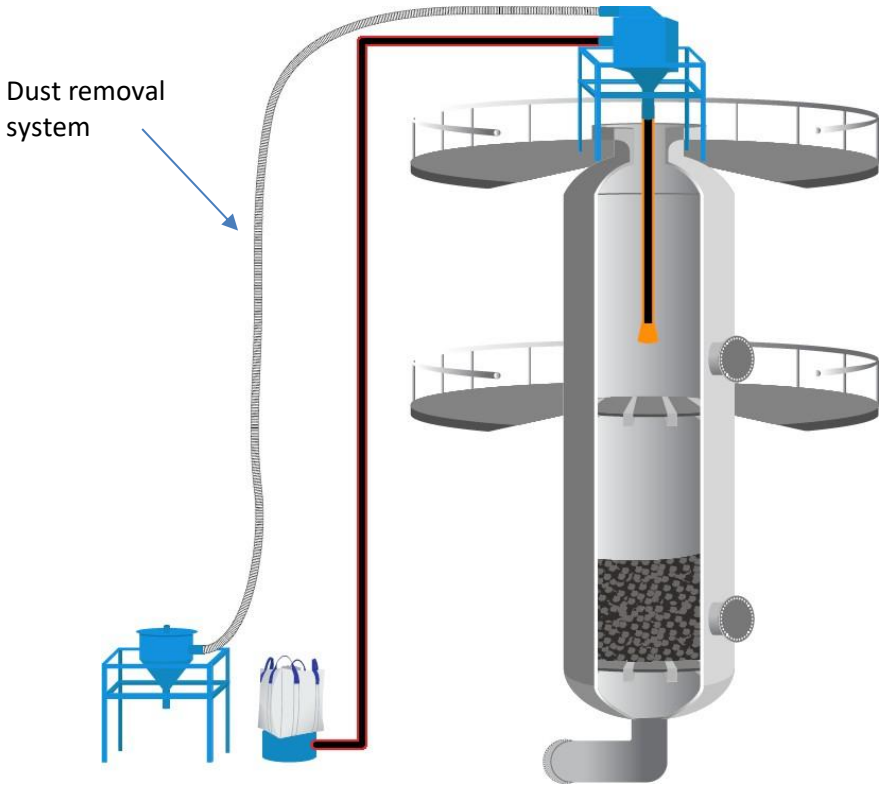

Figure 9: Direct transfer from big bag to reactor. Technology from different catalyst handling companies vary in appearance but work on similar principles.

8.1 Loading directly from bigs bags or drums

The catalyst is transferred directly from big bags as illustrated in below.

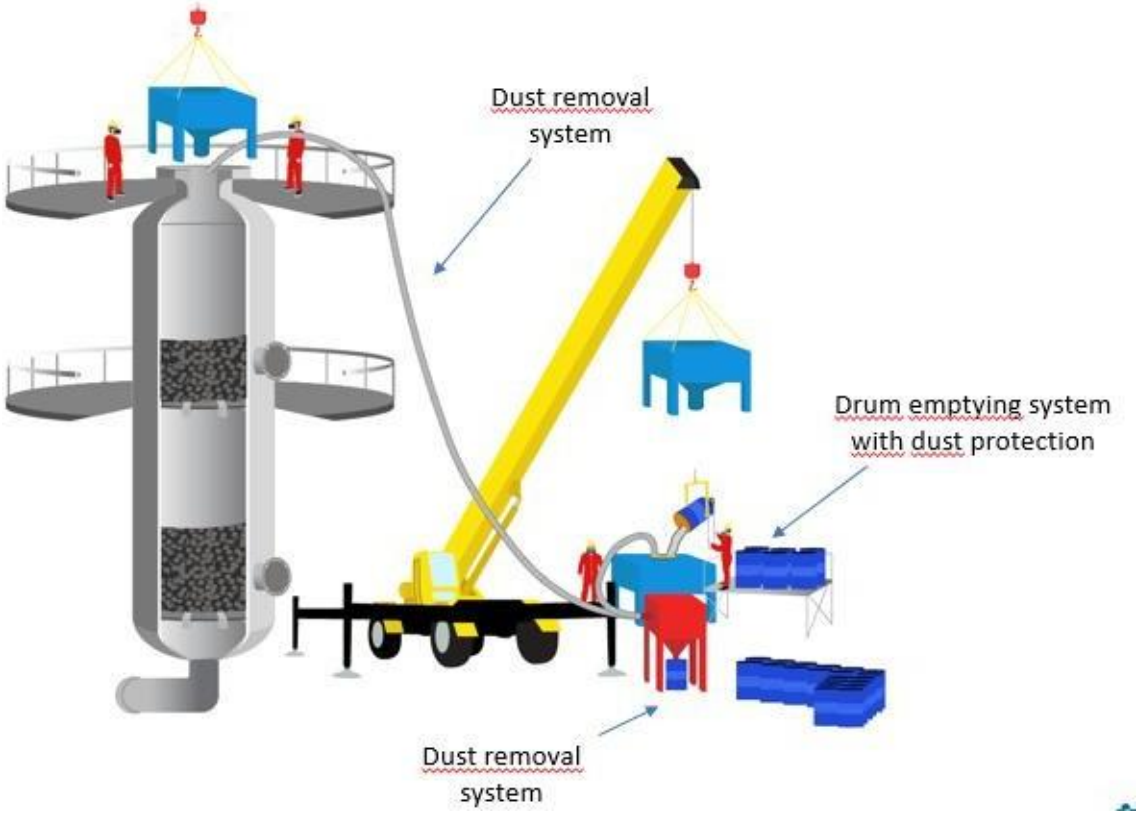

Figure 10: Pre-bagging/filling at ground level where big bag or drum emptying can be better managed and the hopper is lifted by crane.

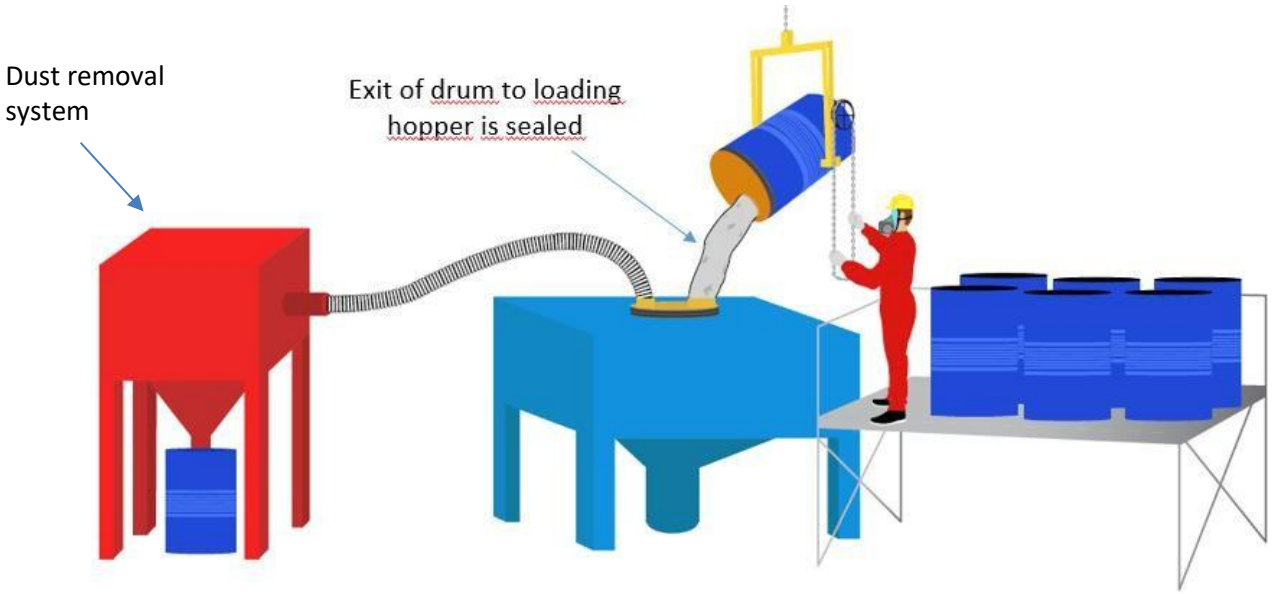

Figure 11: Drum emptying with containment to avoid dust. A lid is placed on the drum that allows the connection to be sealed.

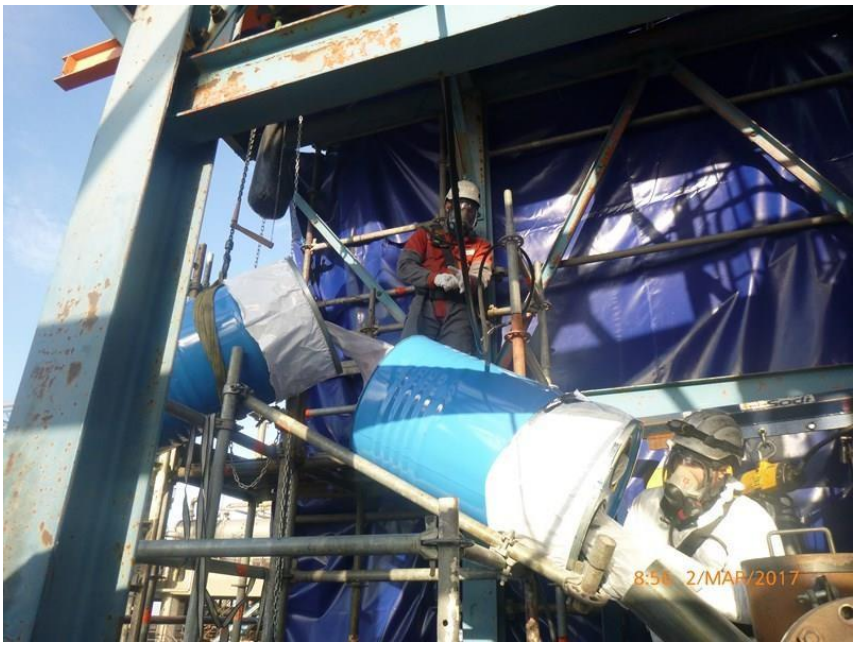

Figure 12: Drum emptying in a difficult location with dust containment. The opening of the drum is enclosed in a sleeve to prevent any dust formation.

Figure 13: Top mounted loading hopper where big bags are transferred to the top of the reactor and discharged into the loading hopper

8.2 Pneumatic loading

This consists of pneumatically conveying the catalyst directly from packaging into the reactor via a hopper. This minimizes operator exposure, environmental impact and the requirement for crane support. This is often carried out by a handling company with low attrition equipment approved by the catalyst manufacturer.

8.3 Automated systems

These are being actively developed to avoid operators entering reactors. Their use normally depends on reactor design and catalyst type, so cannot be used in all cases. They are normally proprietary technology.

8.4 Dense loading method

This involves using a device to spread the catalyst more evenly to reduce void spaces and bridging. The device should spread the catalyst over the surface of the catalyst bed while minimising it by hitting the side walls. As the catalyst bed is denser, more catalyst can be loaded into the same reactor volume. Dense loading can also reduce channeling where poor or segregated packing allows preferential flow through part of the reactor. A denser bed will increase the pressure drop over the reactor bed.

The dense loading technologies differ in their methodology, with some using rotating equipment and others relying on air as a propellant to spread the catalyst. Nitrogen can be used in place of air for self-heating catalysts. Dense loading methods require constant operator attention to regulate the feed rate and avoid surges. It normally requires an operator in the reactor to follow loading. Periodic checking of the level and evenness is required during loading. Advanced dense loading technologies facilitate the catalyst loading while allowing enhanced machine control and catalyst bed profile continuous monitoring. Some specific machines can be controlled with a technician outside the reactor.

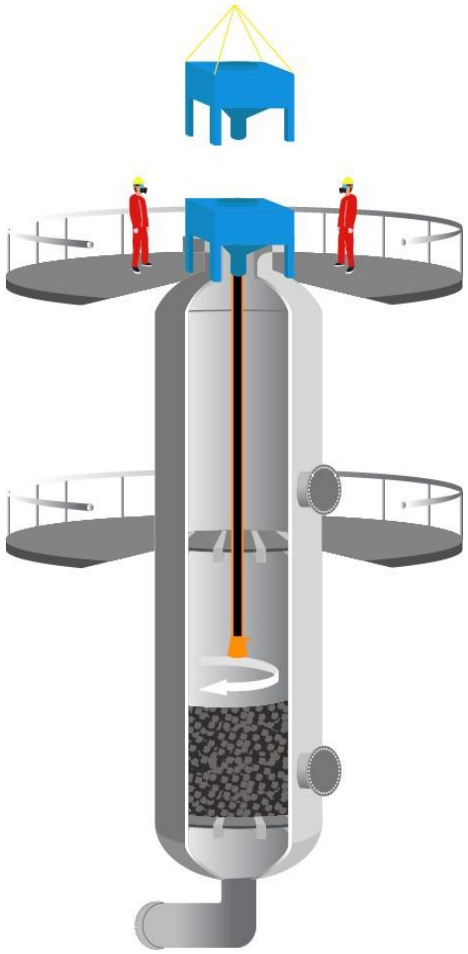

Figure 14: Dense loading method principle.

Figure 15: Dense loading devices.

8.5 Sock loading method

This is where catalyst is transferred from a loading hopper at the top of the reactor into the catalyst bed via a flexible sleeve or sock. It typically consists of a rigid pipe attached to the discharge nozzle of the hopper at the top and flexible sock at bottom to keep it full of catalyst. A spreader device at the end of the sock is normally used to evenly spread the catalyst.

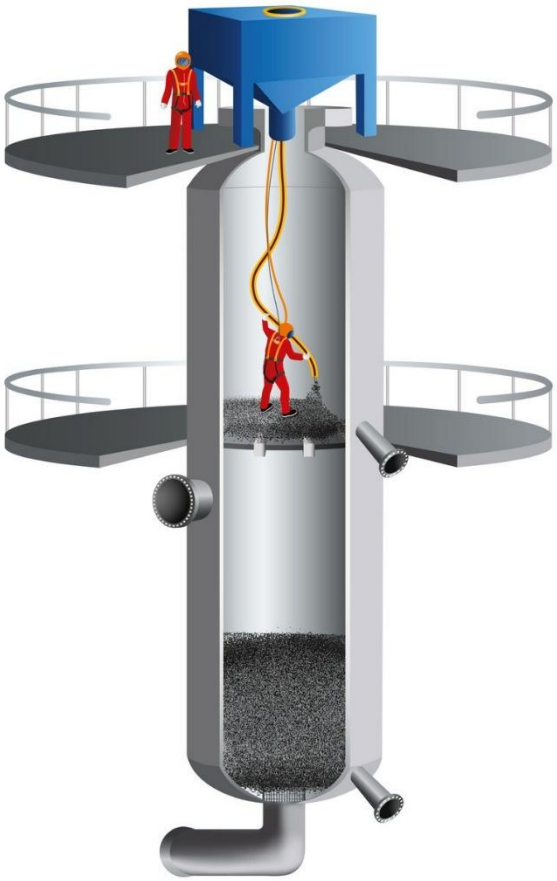

Figure 16: Sock loading principle.

The sock is shortened as operation continues to ensure the drop at bottom of bed is minimised to avoid abrasion and minimise dust formation. The maximum distance between the end of the sock and the top surface of the bed should normally be less than 1 meter. For multiple beds, an operator is normally required

inside reactor to direct the sock. In single beds, it is not normally necessary for an operator to enter the bed, except for levelling. If dense loading is applied, the reactor entry may be avoided.

Loading the grading material at the top of the catalyst bed might be difficult if the gap between the catalyst and the distributor plate is narrow. The operator must crawl at the surface and may not stay in the direct line for extraction.

A specific device allows to load grading materials for bottom and top layers without dust inside the reactor and without full sock. This increases visibility and reduces a lot the risks of falling sock on the technician inside.

8.6 Internals cleaning and boxing-up

The cleaning and closing of the internals, during the loading of the catalysts, is a crucial step to ensure optimal distribution of gases and liquids within the catalytic beds.

Various cleaning techniques, such as brushing, vacuuming, high-pressure washing and cryogenics, are implemented to clean the internals between the unloading and loading phases.

The relocation of internals is carried out in accordance with the mechanical plans provided by the various catalyst manufactures

8.7 Tube reactor/reformer loading

This requires directly filling the catalyst into each individual tube and can be a very labour intensive operation.

This generally involves some specific tools /apparatus to maximize the loading of each tube and ensure that the resulting delta P in each tube is correct.

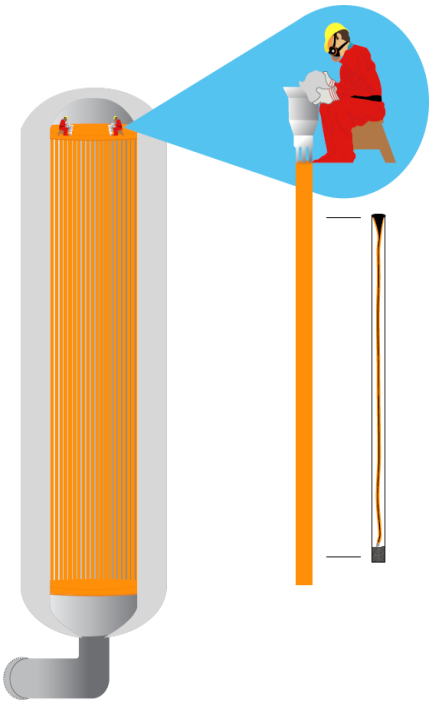

Figure 17: Loading operations for a tubular reactor

Figure 18: Loading of a tube reactor from the top. The flexible duct is the vacuum system for dust removal.

9.0 Catalyst unloading

Before a catalyst can be removed, the reactor must be fully isolated and purged of process fluids. The spent catalyst may also need to be passivated. There are many different reactor designs and the operation has to be adapted to the specific circumstances. Spent catalysts should be loaded into appropriate packaging with regular sampling of spent catalysts. The two main methods are gravity discharging through dump nozzle and vacuuming.

Any technology used for emptying a reactor implies having the actual loading diagram and mechanical drawings of the reactor.

9.1 Catalyst stripping at the end of run

It is recommended that the porosity of the spent catalyst is freed from hydrocarbons, hydrogen sulfide (H_2S), metal carbonyls, hydrogen. Those components are potentially toxic, explosive and/or flammable. Liquids layer at the surface of the grains might lead to sticky agglomeration.
Lower explosion limit (LEL), H2S are checked after reactor opening.

The in-situ stripping is performed at the end of run in two steps 1) at high temperature (> 300°C) under hydrogen flow, 2) low temperature under nitrogen flow.

Some companies propose to skip this stripping procedure and replace it by injecting a proprietary chemical at the end of the run. The self-heating property of catalyst remains and inert entry by an operator is still necessary.

9.2 Catalyst cooling at the end of run

After stripping, the catalyst inventory and the reactor shell need to be cooled down to 1) allow the reactor entering, 2) allow a safe catalyst handling, 3) lower the risk of self-heating.
Cooling is ensured by injecting Nitrogen through the catalyst bed(s). Sometimes, the nitrogen network is not sufficient and the operation could last a long time and sometimes not reach an acceptable temperature.
Cooling operations can be subcontracted to specialized companies. These specialists are equipped with liquid nitrogen tank(s), vaporizer, N2 pump, temperature monitoring, command module.
2 techniques are possible 1) Nitrogen once through injection at low pressure, low feed rate, 2) Nitrogen recycling at high pressure, high feed rate.
These companies can also carry out the hot stripping before cooling.

9.3 Vacuum unloading with inert entry

This requires a vacuum to suck the spent catalyst from the reactor. This can minimise exposure to the operator and environment by directly transferring the spent catalyst including dust from the reactor to the packaging such as drums for regeneration, recycling or disposal. As with vacuum loading, this may cause attrition of the catalyst which may be a factor for regeneration. In some cases, entry to the reactor may be required.

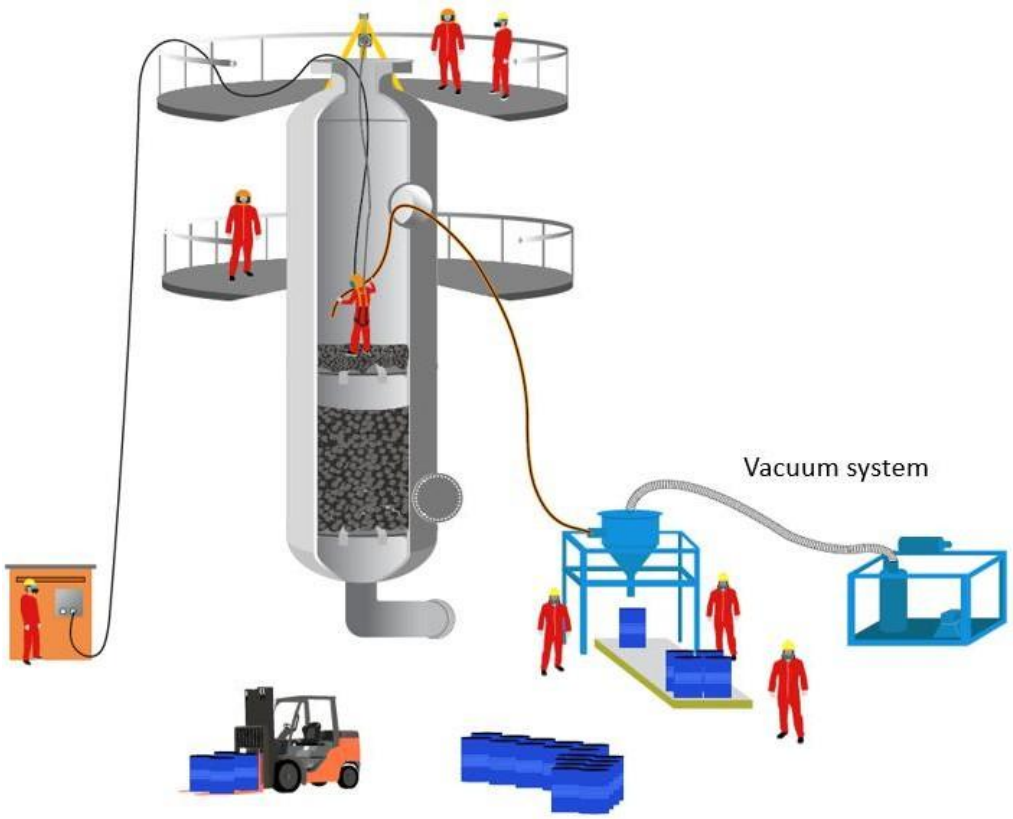

Figure 19: Catalyst unloading under inert atmosphere by vacuum.

Vacuuming with hose passing through the top manhole requires high power that creates loss of catalyst due to attrition / shortening. Vacuuming through dump pipes or lateral manholes is less damaging.

9.4 Vacuuming with no or limited inert entry – Robotic approach

Some companies have developed robotic systems that ensure the vacuuming of the catalyst. However, for some robotic systems, distributor plates, support grids, and quench zones still need to be opened under inert atmosphere. Plates that do not need manual intervention are not available currently but are being researched.

1) A motorised arm is installed at the top of the reactor connected to a vacuum truck.

Such a technique still requires the opening of the plates under Nitrogen and is limited to a top bed and /or single bed reactor.

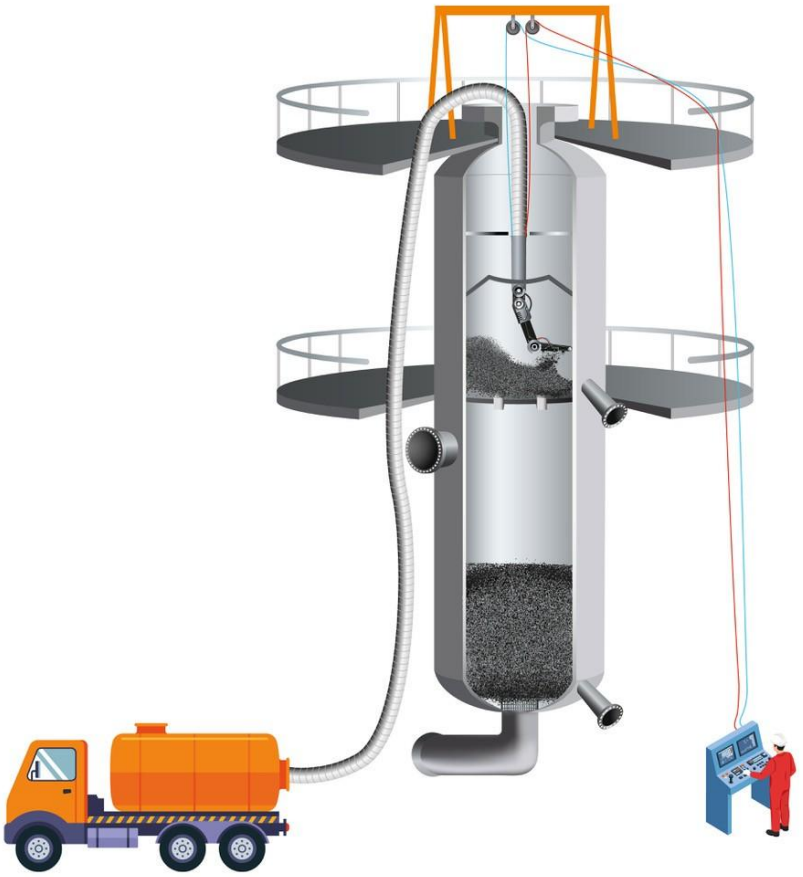

Figure 20: Motorized arm

2) A remote-controlled caterpillar connected to a vacuum truck moves at the surface of the catalyst while sucking. A camera is introduced in order to move the caterpillar.

Figure 21: Caterpillar vacuum device scrawling at the surface of the catalyst

9.5 Gravity unloading

Gravity dumping is the fastest and safest way to unload some catalysts from a reactor. It is the least expensive technique, and the quality of the recovered catalyst is optimal. This technique is the first to consider.

This requires a nozzle at the bottom of reactors or at the bottom of each bed for multiple bed reactors. Gravity discharging requires constant monitoring to ensure the catalyst is unloading evenly. Not all of the catalyst can be removed this way and the balance must be removed by vacuuming, shoveling or alternative technologies presented before.

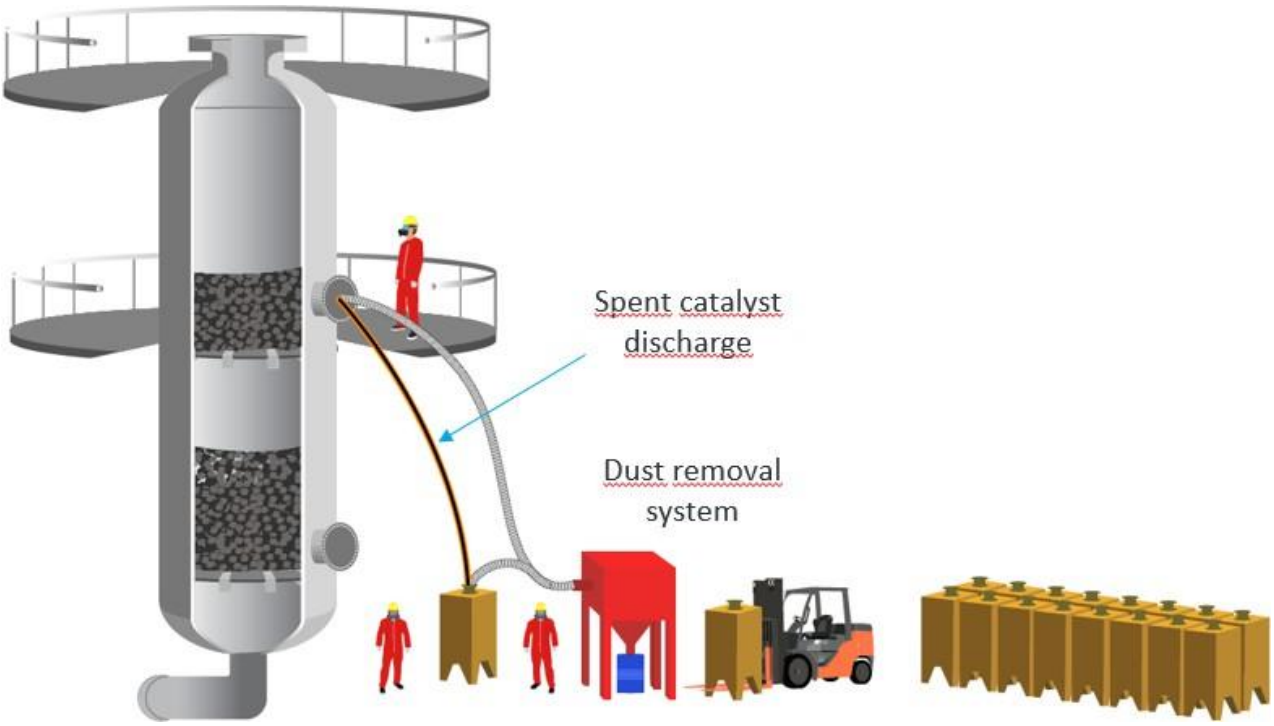

Figure 22: Spent catalyst unloading by gravity into containers.

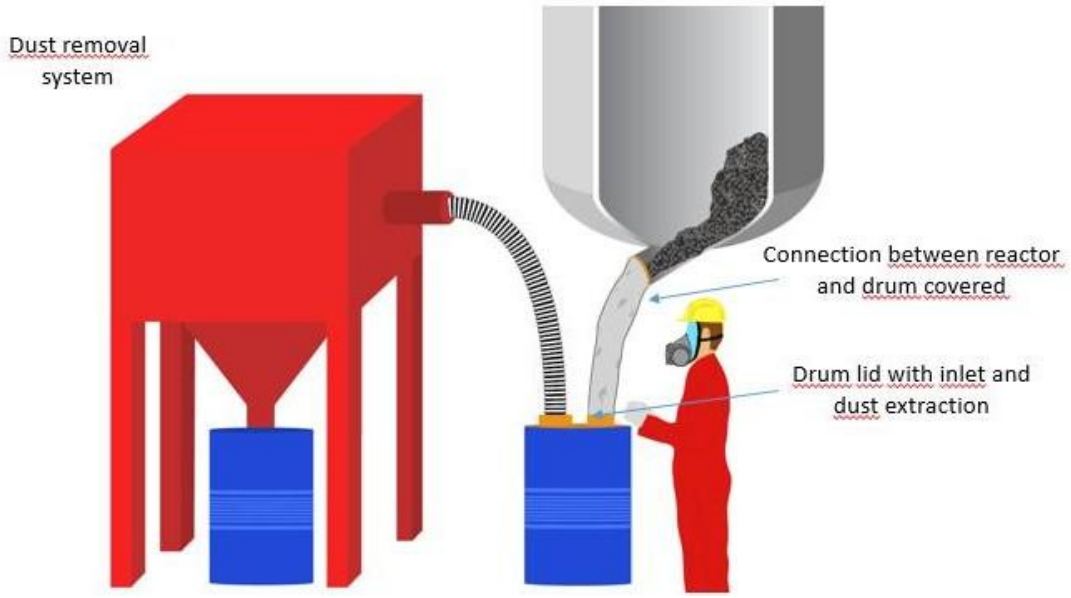

Figure 23: Catalyst unloading by gravity.

In case of horizontal dump nozzles, catalyst cannot flow by gravity. Some technologies are available.

1) A catalyst fluidizing device connected to horizontal dump pipe extracts the particles.

The fluidization is achieved by a flow of nitrogen inside a penetrating tube and the fluidized catalyst is able to flow out of the reactor by applying a small pressure drop/ delta P over the pipe. A cyclone connected to a vacuum truck traps the dust to limit its dispersion. This technology preserves the catalyst's integrity.

Figure 24: Fluidizing device inserted at a horizontal nozzle

2) An endless screw can be introduced for emptying a fraction of the bed (dig-out left over). Due to crushing between screw and auger, the use of such a tool damages the catalyst.

Figure 25: Endless screw for horizontal nozzles(Drawing to be redrawn)

End of natural gravity dumping

Natural gravity dumping stops when the angle of repose of the catalyst is reached. Depending on the reactor design the remaining quantity (so called dig-out) might be very important and sometimes even bigger than the amount collected by gravity.
An operator must dive inside the reactor to shovel or vacuum the left over dig-out. Diving is done under nitrogen atmosphere or under air if the wet unloading.
Before diving, a visual inspection must be performed to validate further operations. Activation of CO2 cartridges (see paragraph …) can be activated to clear any retention and lower the angle of repose.

To limit inert entry 2 technologies exist aiming at removing the dig-out through the dump pipe.

1) an endless screw system that can be introduced through the dump pipe. The rotating screw unload most of the dig-out without reactor entering.
   The absence of auger reduces catalyst crushing.

Figure 26: Endless screw excavating the dig-out after gravity dumping

2) A vacuum hose introduced through the dump pipe and crawls on the surface of the catalyst.

The hose connected to the vacuum pump is remotely controlled by a camera introduced through the pipe or any other port. Translation and rotation of the hose are ensured by hydraulic engines bolted to the nozzle. The sucking mouth can reach all locations where catalyst or inert material remains.

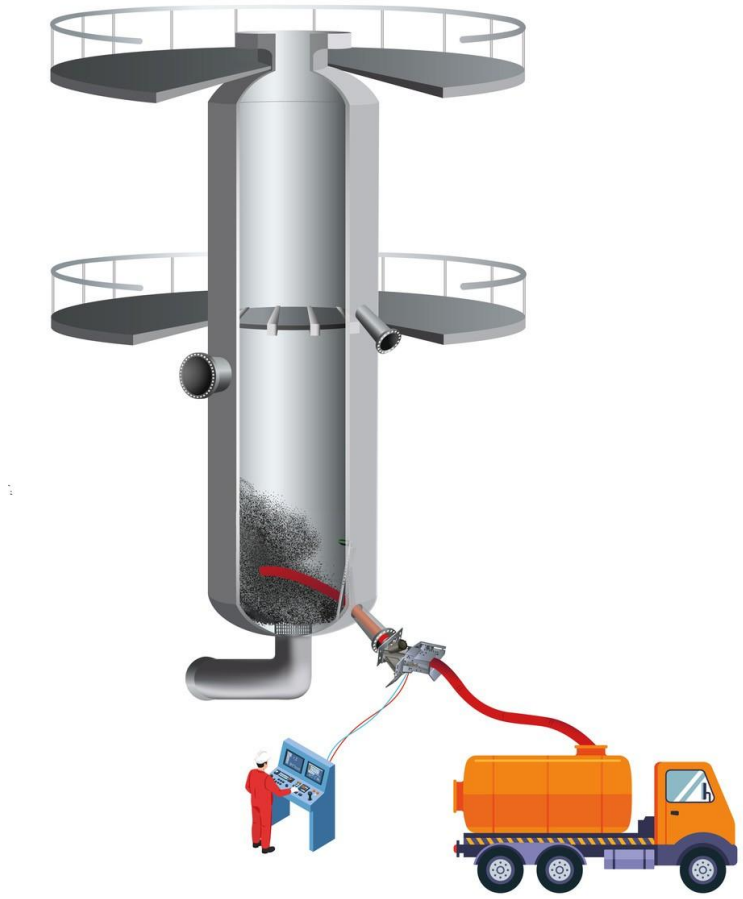

Figure 27: Vacuum hose introduced through the dump pipe

The two above techniques do not require the reactor to be opened and can be operated in multibed configuration simultaneously.

Gravity dumping monitoring

When the catalyst is not agglomerated and behaves as a free-flowing material, the pattern of the unloading looks like a sand-timer. When the dump nozzle is opened a vertical chimney along the bed and a funnel shape at the surface are formed. The upper layers are unloaded before the lower ones until the angle of repose of the catalyst is reached.

Figure 28: Gravity dumping of free flowing catalyst
LIFO Pattern

It is very important to be aware of this flow pattern. The flow behavior of catalyst can be observed/monitored depending on the possibility of entering the reactor under inert atmosphere.

1) If entering the reactor is possible, the easiest way to monitor the gravity dumping is to stop the flow from time to time and observe the surface of the catalyst bed, appearance and depth.

2) If entering is not possible (or in case of parallel dumping) the theoretical pattern of the catalyst dump can be followed by 3 parameters evolving during the discharge: 1) samples observation to detect upper layers and or gradings, 2) Actual unloaded volume versus theoretical, 3) Temperature trends showing the transition between buried / emerging thermocouples as dumping continues.

Depending on the information collected during the progress, it is possible to make sure of the free-flowing behavior or reveal some catalyst retention that will have to be addressed.

Good monitoring allows unloading beds in parallel or unloading lower beds before upper ones.

9.6 Wet unloading

In some cases, spent catalyst can be wetted to minimize dust formation and limit self-heating behavior. Wetting also allows the entering under normal atmosphere.

It makes sense to limit the wetting of the catalyst to the fraction which does not come by gravity. Doing so the quantity of reusable catalyst will be maximized.

To be noted :

- Wet catalyst remains a self-heating material according to UN test
- Wet catalyst is roughly 20 % denser than dry spent catalyst. Packaging type, mobilization, transportation must be adapted.
- Wet catalyst is not free-flowing and it might be difficult to empty the containers/drums/bags, move the catalyst at regeneration premises.
- Free water (outside the porosity of the grains) is contaminated by hydrocarbons and metals. It must be collected and treated. Additional costs are not negligeable.

Typical procedure consists in injecting water from the bottom of the reactor up to the top flange of the reactor, allowing a soaking period, and draining until the level reaches the location where some activities such as plate / grids opening / catalyst vacuuming must be achieved.

In terms of safety, although the inert atmosphere is not present, breathing apparatus must be worn and work inside capacities rules remain mandatory. Water makes the surfaces slippery.

Flooding a reactor requires a large quantity of demineralized water, big tanks, additional piping, pump, instrumentation. It may create some difficulties in terms of space, more logistics, more contractors.
Contaminated wastewater must be retreated.

Care needs to be taken to avoid excess contaminated water.

9.7 Catalyst Passivating

Some companies propose limiting the self-heating behavior of the spent catalyst by adding in the porosity and outside some proprietary chemical compounds. This is done at the end of the run in replacement of the stripping step.

The coated material may have lost its self-heating property and if so can be unloaded under normal atmosphere.

A very sensitive point is the risk of having some fraction of the catalyst which is not coated (potential maldistribution) than can lead to unexpected reactions.

In addition, it may be impossible to regenerate the catalyst for further reuse. Free flowing of the impregnated catalyst is questionable.

Chemical Passivation and Decontamination Techniques

These technologies chemically neutralise self-heating behaviour and remove hydrocarbons, H_2S and other reactive species.

Chemical Passivation and Protective-Film Methods

Certain chemical passivation techniques apply a **temporary protective layer** to the catalyst and reactor internals. This layer reduces the tendency of spent catalyst to re-oxidise when exposed to air. Once contaminants and reactive gases are sufficiently removed and temperatures are controlled, the catalyst can often be unloaded under air rather than nitrogen. These methods may also reduce the need for high-temperature stripping steps and can shorten turnaround time.

Oil-Based Passivation Using Carrier Fluids

Some passivation approaches use a **circulated carrier oil** combined with oxygen-blocking additives. These additives form a thin organic film on the catalyst surface, reducing the heat release during oxidation and lowering the risk of self-heating behaviour. In many cases, this enables unloading under normal atmosphere in multi-bed reactors after appropriate cooling and gas checks.

Integrated Chemical Cleaning and Decontamination Processes

There are chemical cleaning systems designed to **remove hydrocarbons, volatile organic compounds, sulfides, and other reactive species** from reactors. These processes typically combine cleaning and passivation in one step. They lower flammability indicators (such as Lower explosion limit (LEL)values) and reduce toxic gases, making it possible to open the reactor and unload the catalyst in air without an inert atmosphere. These combined methods can also reduce the total change-out duration by eliminating or shortening conventional purging steps.

Vapour-Phase and Liquid-Phase Chemical Cleaning

Vapour-phase or liquid-circulation cleaning techniques use **biodegradable, non-hazardous chemical agents** to dissolve and neutralise hydrocarbons, iron sulfides, hydrogen sulfide and similar contaminants. By reaching difficult internal areas and catalyst beds, these methods prepare the reactor for safe air entry and catalyst evacuation without the need for inerting.

9.8 Agglomerated catalyst

In some cases, the catalyst can be agglomerated in the reactor and techniques are required to break it up to allow emptying. Catalyst agglomeration might be caused by different phenomena:

1) Presence of material coming with the feed such as iron species, olefins, salts.
2) Catalyst fines due to catalyst attrition that occurs during loading and or compaction during the run
3) Extra granular coking
4) Catalyst sintering
5) Combination of above

The first point is essentially noticed in the upper layers of the inventory; other causes concern the whole

inventory.

The pressure drop over the reactor should be tested prior to commencing operations. Specialized techniques may be required to loosen the catalyst.

An operator should not enter a reactor that has a high wall of agglomerated catalyst because this wall could fall and crush the operator on collapse. The wall height should be less than 1m as shown in Figure 29.

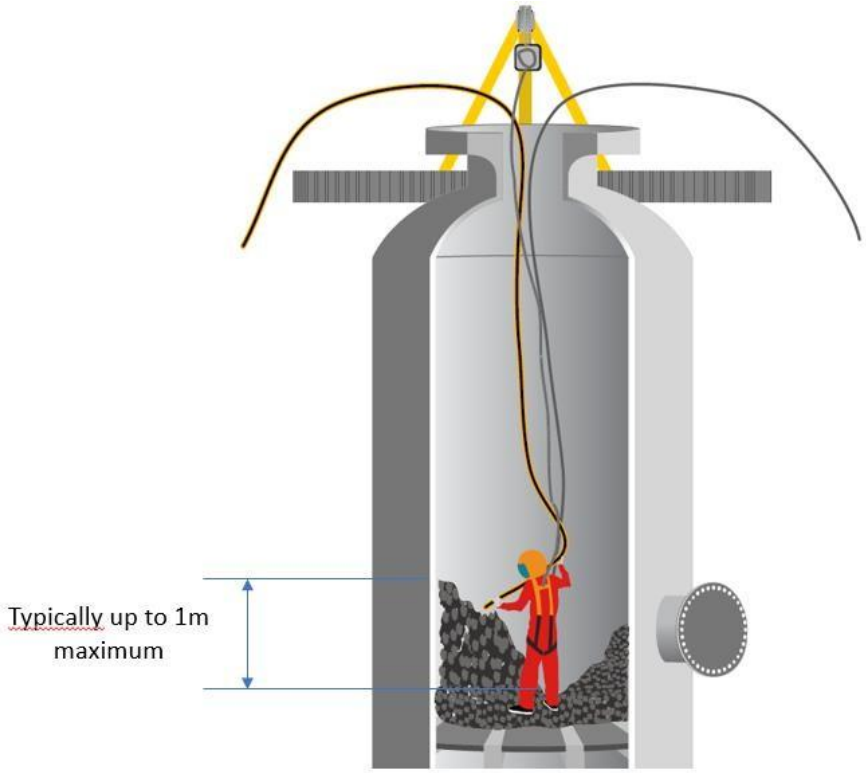

Figure 29: A high wall of catalyst that could crush the operator

An operator should not enter a reactor when a cavern has been formed. A cavern formation can be suspected when the surface of the bed is still horizontal and some catalyst has been gravity dumped. A cavern can be considered when the extracted volume of catalyst corresponds to a height of 1 meter as shown in Figure 30.

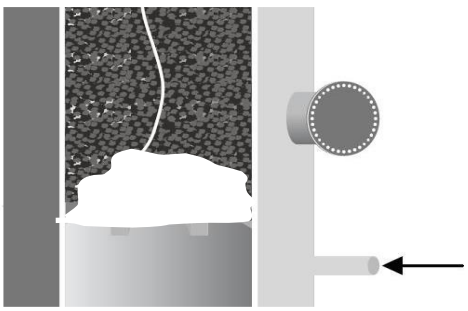

Figure 30: A cavern formed at the bottom of the bed

9.9 Addressing a catalyst agglomeration

- 1 Techniques based on the effect of a sudden expansion of gas.

Two techniques are based on the actual explosion of either a stoichiometric mixture of Propane and Oxygen or dynamite / TNT. These techniques are rarely utilized in refinery for safety reasons.

The most used technology is with CO2 cartridges. In that case 1.3 kg of Liquid CO2 turns to a gas phase within few hundredths of a second. The instantaneous expansion of the gas fragilize the catalyst build-up and develops a shock wave in the reactor.

CO2 cartridges are used in different ways:

- From the dump nozzle to prime a gravity dump or resume a flow that has stopped. Vertical catalyst retentions (pillars, caverns, cliffs) can be addressed as well from the dump pipe, Figure 31
- From the top of the bed to desegregate the catalyst build up before vacuuming, Figure 32

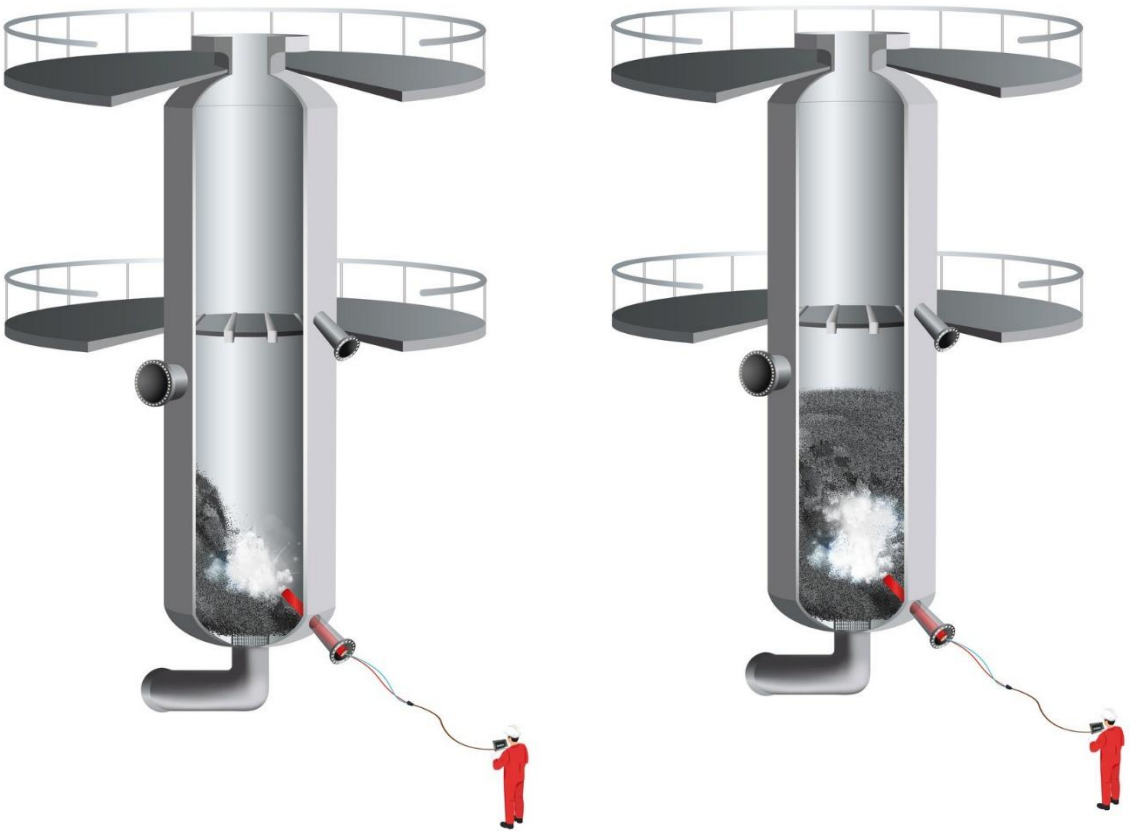

Figure 31: CO2 cartridges through the dump pipe to prime the dumping or clear vertical retention

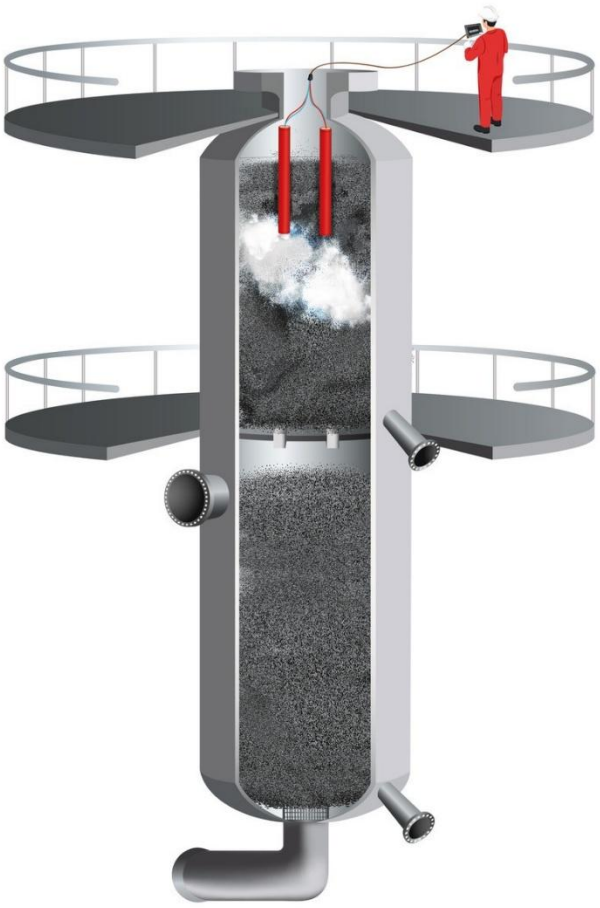

Figure 32: CO2 cartridges from the top to facilitate the vacuuming

The use of this technology requires specific equipment (among them : specific dumping valve and extension poles), skilled and qualified teams.
Video inspection is mandatory.

- 2 Water hydrojetting

The technique comes from the cleaning activities.
Hydrojetting can be applied from the bottom of the bed, in pulse or continuous mode.
Hydrojetting is also used from the top of the reactor with a specific nozzle (Barthod head) as a continuous defragmentation in parallel with discarding the mix of catalyst and water.

Both applications destroy the catalyst which can not be reused and generate large quantities of contaminated water.

9.10 Spent Catalyst conditioning

Spent catalyst should be packed in UN approved containers (1 to 2.5 m3) or drums (200 liters). A plastic liner inside the drum is recommended. Appropriate labelling (id, numbering, risk) is mandatory.

Unloading is associated with dust emission. As the reactor is slightly pressurized by Nitrogen, the dust is flushed out through any slot in the path from dump nozzle to container or drum. The lower the nitrogen intake, the lower the exposure to dust and nitrogen.

Dump valves, connecting sleeves, PE liners must be leakproof. The ceiling of the container or drum must be sucked, filtered. Flushing nitrogen inside the container or drum is not necessary.

Once full, UN approved container or drum must be closed. A handful of carbon-ice may be used to purge the atmosphere before closing.

Operators in charge of filling containers or drums must wear a dust mask MP3 or preferably a breathing apparatur, protective clothes (Tyvex type). Work at height is present most of the time.

Logistic at ground level depends on the reactor environment and the equipment brought by contractors. Housekeeping is a key point.

10.0 High exposure risks

The areas of highest risk of exposure to catalysts.

Loading	Unloading
Pre-bagging/filling the intermediate lifting hopper from big bags or drums	At the manway or point of entry into the vessel
Transfer of catalyst from lifting hopper or big bag to the loading hopper or vessel	Working within the vessel for unloading the catalyst, cleaning after unloading and internal repairs or modifications
At vessel entrance man way	When exiting the vessel and removing protective clothing
Inside the reactor during loading	Around the dump nozzles and spent catalyst packaging areas
	At the outlet of the vacuum cyclone where spent catalyst is packaged.
	At dust collection and vacuum systems filtration bag house when cleaning
	All equipment cleaning
	Spillages and the cleaning up of spilt catalyst

There may also be a risk of catalyst exposure during maintenance operations such as repairs to pipework and instruments linked to the catalyst reactor.

11.0 Personal Protective Equipment (PPE)

It is very important to have comprehensive safety equipment adapted to the specific requirements. A detailed check list is included in the Annex 1 - Best practice list.

The following table is the typical Personal Respiratory Equipment (RPE) employed. This should be reviewed in each case and fit tests are required for all respiratory equipment.

Situation	Location	Respirator
Inert atmosphere such as nitrogen	Inside reactor	Integral helmet and appropriate air supply
	Top side near open manway (around 1.5m)	
	Near dump nozzle (around 1.5m)	
	Top side away from open point of reactor	Full or half face P3 with fit test
Other cases subject to risk assessment	Inside reactor	Other breathing apparatus or respirator
	Top side near open manway (around 1.5m)	
	Near dump nozzle (around 1.5m)	
	Top side away from open point of reactor	Full or half face P3 with fit test
Screening/sieving Operator	High risk cases	Integral helmet and appropriate air supply
	Other cases subject to risk assessment	Full or half face P3 with fit test
Pre-bagging Operator		Full or half face P3 with fit test
Ancillary Operator		Full or half face P3 with fit test

The United Kingdom Health and Safety Executive (HSE), Respiratory protective equipment at work, HSG53, a practical guide, is a useful document on the use of Respiratory protective equipment (RPE).

Personal protective equipment should comply with applicable standards

Safety equipment	Applicable standards
Overall PPE regulation	Regulation (EU) 2016/425 on Personal Protective Equipment (PPE)* CE Approved equipment should used.
Full breathing apparatus	EN 14593-1: 2018 Respiratory protective devices. Compressed air line breathing devices with demand valve. Devices with a full face mask. Requirements, testing and marking United Kingdom Standard Assigned Protection Factor 2000 (APF 2000) or equivalent. EN 136:1998 Respiratory protective devices. Full face masks. Requirements, testing, marking EN 402:2003 Respiratory protective devices. Lung governed demand self-contained open-circuit compressed air breathing apparatus with full face mask or mouthpiece assembly for escape. Requirements, testing, marking
Respirators/Filters	EN 136:1998 Respiratory protective devices. Full face masks. Requirements, testing, marking EN 140: 1999 Respiratory protective devices. Half masks and quarter masks. Requirements, testing, marking EN EN 143:2021Respiratory protective devices. Particle filters. Requirements, testing, marking EN 12941:1998+A2:2008 Respiratory protective devices. Powered filtering devices incorporating a helmet or a hood. Requirements, testing, marking EN 12942:1998+A2:2008 Respiratory protective devices. Power assisted filtering devices incorporating full face masks, half masks or quarter masks. Requirements, testing, marking
Protective suits	EN ISO 13982-1:2004+A1:2010 Protective clothing for use against solid particulates. Performance requirements for chemical protective clothing providing protection to the full body against airborne solid particulates (type 5 clothing) (example Tyvek) or equivalent
Eye wear	EN 166:2002 Personal eye protection. Specifications
Head	EN 397:2012+A1:2012 Industrial safety helmets
Footwear	EN ISO 20346:2014 Personal protective equipment. Protective footwear
Gloves	EN 388:2016 Protective gloves against mechanical risks EN ISO 374-1:2016 Protective gloves against dangerous chemicals and micro-organisms. Terminology and performance requirements for chemical risks
	Other EN standards maybe applicable.

* There is a transition period of 1 year from 2 April 2018 to 20 April 2019, where both the old Directive and the new Regulation are applicable. Therefore PPE designed and manufactured in accordance with Directive 89/686/EEC can still be placed on the market until 21 April 2019.

Annex 1 - Best practices list

The following is a list of items that should be considered in catalyst handling operations.

REACTOR AND SITE DESIGN

Reactor design	
Installation and removal of the catalyst is taken into consideration in the design of the reactors	
Ensure catalyst can be loaded easily to maximise process performance	
Bottom dumping nozzles to allow spent catalyst to be unloaded by gravity	
Side discharge nozzles and access manways for multi-bed units	
Suitable height and space under the reactor for bottom discharge if applicable	
Will operators need to enter reactor during loading and unloading	
Electrostatic discharge	
Site design	
Catalyst reactors have good access platforms and stairways with space for operators and equipment	
Clear space around the top of the reactor for movement by equipment such as cranes	
Well located structures, piping and electrical cables	
Access around reactor base for equipment such as cranes, forklifts and temporary catalyst storage	
Allow for the working area to be cordoned off during loading and unloading operations with minimum disruption to other operations	
Clear surfaces to allow any spillage to be easily cleaned up	
Drain design to allow easy covering in case of spill	

PREPARATORY ORGANISATION

Pre-visit – items to cover	
Ensure a pre-visit takes place	
Catalyst type including Safety Data Sheet (SDS)	
Expected condition of spent catalyst	
Reactor design	
Process requirements such as isolation of the reactor including utilities	
Catalyst installation and removal method	
Access for operators and equipment	
Inert atmosphere/confined space entry requirements	
Review of history and experience of previous operations	

Method statement	
Prepared prior to interventions	
Standard procedures adapted to specific site requirements	
Permit system in place for all reactor entry	
Risk assessment	
The task	
Work environment	
Working materials and tools	
Suitability of those carrying out the task	
Inert atmosphere/Confined space entry	
Catalyst Safety Data Sheet (SDS)	
Evaluation of the potential condition and hazard of spent catalyst	
Environmental risk	
A safety meeting including site safety representative before commencement of the work	
Work in confined space/inert atmosphere	
Detailed procedures for use of inert/nitrogen	
Open manholes, weather protection and under vessels are treated as inert atmosphere	
Open manholes have barriers with warning labels	
Rescue plan	
Location of trained responders on site	
Location of trained responders off site	
Rescue equipment available	
Vessel evacuation procedure	
Compatibility of on-site rescue equipment with catalyst handling equipment	
On-site rescue personnel have at least the same level of PPE protection as those they are rescuing	
On-site rescue personnel with breathing apparatus have at least the same level of air duration as those they are rescuing	
Accessibility of the location	
Use of retrieval systems	
Work organisation	
Work undertaken by suitably qualified technicians	
Clearly define Supervisor for the operation	
Clearly define responsible site representative/supervisor	
A clear hand over and records of process checks and isolation before handover	

Automated system possible to avoid operator entry	
Record keeping	
All key steps and interventions should be recorded	

PROCESS AND PACKAGING

Process	
Check process safe before commencing operations	
Pressure drops checks to ensure no crust build up	
Sampling programme for spent catalyst	
Spent-heating catalyst filled into drums/bins under a nitrogen blanket	
Packaging	
Includes big bags (FIBC), drums and forklift movable 1 – 2m³ bins	
Designed to minimise the changeover of bags and drums to reduce exposure	
Dust extraction with bag filtration used during emptying	
Receiving hopper designed with a cover to minimise dust	
Big bags with a double outlet sleeve (the outer sleeve is designed to be clamped during emptying help to prevent dust)	
Drum emptying with suitable equipment to minimise dust including extraction	
Screening device to prevent foreign matter entering the reactor	
Verify if packaging can be directly re-used for spent catalyst and other waste	
Packaging is certified	
All 4 corners of the empty big bag are shaken vigorously to remove remaining material (This is the main location for residues)	
The empty big bag is folded carefully immediately after discharge and placed into a polyethylene bag and sealed (Empty unfolded big bags discarded for later sorting and folding should be avoided)	

DUST AND ENVIRONMENT

Dust minimisation	
Dust source can be removed	
Number of transfer operations minimised	
Pre-bagging equipment has containment/covers	
Dust removal equipment at pre-bagging area (loading)	
Dust removal equipment at reactor loading point (loading)	
Dust removal equipment at other reactor openings	
Dust removal equipment at reactor discharge point (unloading)	
Dust removal equipment for receiving vessel such as drum (unloading)	

Dust removal equipment maintenance and cleaning programme	
Direct loading of the collected dust into receiving vessel such as drum	
Wind protection screening to prevent fugitive emissions	
Settled dust and spill management	
Cover sheets for difficult surfaces such as gratings and equipment	
Drains covers	
Spills cleaned immediately to avoid dispersion by shoes, vehicles and wind	
Spill cleaned by vacuuming to avoid dust and minimise residues. No sweeping.	
Disposed in an appropriate way	
Waste management (see Catalysts Europe - Guidelines for the management of spent catalysts)	
Spent catalyst in appropriate containers such as drums or bins	
Used packaging collected and disposed of	
Used personnel protective equipment collected and disposed of	
Handling equipment and working area cleaned by vacuum prior to demobilisation and handover	

OPERATOR HYGIENE

Operator hygiene facility located near operations	
Residual dust vacuumed before removal of coverall	
No eating or drinking in the loading area	
Facility for dust removal	
Containers for used personnel protective equipment	
Dirty changing area	
Wash area	
Clean changing area	

SAFETY SYSTEMS AND EQUIPMENT

Safety systems	
Documented safety system	
Third party approved safety system such as ISO or other country specific standards such as VCA in the Netherlands	
Contractor safety system, if applicable	
ISO45001 (previously OHSAS 18001) certification	
Regular audits and checks are carried out	
Training reactors used for initial and refresher training	
Initial training program	

Refresher training program	
Personal Protective Equipment (PPE)	
Eye and face protection	
Hand protection (Gloves to suit the specific requirements)	
Hearing protection	
Safety shoes	
Head protection	
Coverall	
Coverall – Anti-static flame resistant fabric when risk	
Coverall - Chemical resistant disposable coverall when required	
Respiratory equipment suitable for the requirements	
Fit test to check that the required equipment fits properly on each individual	
PPE such as coveralls replaced when torn or damaged	

TRAINING AND QUALIFICATIONS

Training requirements	
Documented training requirements	
Documented competency assessments	
Minimum training and experience periods	
Supervisor/Operator training requirements	
Basics of breathing and toxicology training	
Safety Data Sheets (SDS)	
Threshold limit values and explosion risks	
Regulatory requirements	
Catalyst handling training	
Identification and risks of confined spaces	
Measurement of toxic and harmful gases and vapours and explosion risks	
Making confined spaces with explosion risks inert	
Training on all equipment and its use	
Safe work methods	
Practice in training reactors	
Emergency procedures and rescue operations	
Refresher Training	

Ancillary operator training requirements	
Basic training and awareness of listed areas	

INERT ENTRY, IF APPLICABLE

Inert entry equipment	
Anti-panic lockable integral helmet with breathing apparatus	
Minimum of 3 independent air sources	
Self-contained cylinder (escape set)	
Apparatus operates under positive pressure	
Integral communication system between Standby Operator, Communications Operator and Life Support Operator	
Constant monitoring of O_2	
Constant monitoring of H_2S (if assessed as required)	
Constant monitoring of CO (if assessed as required)	
Constant monitoring of Lower Explosion Limit (LEL) if shown to be a risk	
Constant monitoring with radio	
Recording system with radio	
Constant monitoring with camera particularly if no direct sight	
Recording system with camera particularly if no direct sight	
Equipment is explosive proof where the risk is identified	
Fit test to check that the required equipment fits properly on each individual	
Full body harness	
Body harness certification	
Retractable fall arresters	
Permanent anchor point for retrieval system	
Certified anchor point	
Good arrangement for A frame temporary anchor point	
Intrinsically safe lighting	
Cover with lock for the manhole to prevent unauthorised access	
Warning signs	
Rescue stretcher or rescue triangle or similar	
Daily inspection with maintenance and testing after each project	

Life Support System (LSS)/Standby Operator responsibilities	
Strictly control entry into inert atmosphere	
Immediately control the withdrawal of personnel when exposure to hazards being monitored or tested goes above or below safe levels	
Remain at his post at all times when personnel are operating in inert atmosphere	
Maintain constant communications with personnel in the inert atmosphere	
Have an established means of raising the emergency rescue team or site rescue service	
Have a thorough understanding of the rescue plan and his/her involvement	
Ensure that the means of entry into inert atmosphere is signed and any access is restricted during periods when personnel are away from the confined space	
Top Side Supervisor or Communications Operator responsibilities	
Record all entries and exits made on the entry log and ensure that personnel are wearing the appropriate safety equipment for entry	
Have a thorough understanding of the rescue plan and his/her involvement	
Hand over the log to oncoming Communications Operator (works continuing) or to his supervisor at the end of the operation	
Remain at his post at all times when personnel are operating in inert atmosphere	
Life Support Operator responsibilities	
Remain in the vicinity of the Life Support Unit at all times when personnel are operating in inert atmosphere	
Ensure that the air supply is guaranteed	
Have a thorough understanding of the rescue plan and his involvement.	

MONITORING

Medical monitoring	
Regular medical examination	
Eye Exam	
Blood Pressure (BP)	
Audiogram (dB Hearing Test)	
Electro-Cardio Gram (ECG)	
Pulmonary Function Test (PFT)	
Physical Examination	
Stress Test (Stamina and Recovery)	
Qualitative Urine Sample (Sugar & Glucose)	
Quantitative Blood Sample (Liver and Blood Count)	

Bio-monitoring	
Regular bloods and urine tests for catalyst substances as required	
Exposure monitoring	
Regular Occupational Exposure Monitoring of personnel involved in operations	
Tests that Operators are safely working below the Occupation Exposure Limit (OEL) for substances being handled based on the information in the Safety Data Sheet and process substances that may be present such as benzene	