# Compressors And Silent Root Causes For Failure

The number one **silent root cause** killer of compressors (both reciprocating and centrifugal) in chemical plants, refineries, and gas processing plants is inadequate knockout drum design. Knockout drums are also called knockout pots, surge drums, separator tanks, separator pots, demister separators, or gas cleaning equipment all serve the same purpose of gas-liquid separation.

The following compressor comments apply to large reciprocating and large centrifugal compressors above 125 horsepower and above 35 psig pressures. It is difficult to prove the **silent root cause** issue by objective evidence of target capture devices installed inside the flow lines to the compressor, thus the issue must be inferred from other experiences.

We know from long experience that steam turbine blades/vanes operating in saturated steam are eroded by the impact of saturated steam (water) particles. Wear resistant alloys are needed on the leading edges of blades/vanes to slow down erosion while running for long periods though a “rain shower”. This says the size of particles is important.

We also know that small flying insects (lovebugs) in warm, moist climates during the summer splatter automobile windshields and upon impact break into even smaller debris that the coat automobile windshields and clog radiator intakes both problems require immediate maintenance. The 1) particle sizes and 2) flow of debris are both problems which require maintenance solutions. Who solves the particle size and flow issues for a compressor to prevent compressor failures?

In the medical field, a frequent finger pointing exercise exists among doctors. The argument goes this way:

> A cardiologist does not want his patient to die from a heart attack; however the patient may die from kidney failure stemming from medicines given by the cardiologist to prevent the heart failure.

So the finger pointing goes on in every field—it's just not peculiar to engineering!

In process plant designs chemical engineers are called upon to design the process for flows. The chemical engineer doesn't want the process to fail, but often the lack of expertise in some areas (such as knockout drum designs) often transfers the failure to a down stream compressor because of inferior knockout drum design. The knockout drum becomes a **silent root cause** of failure because of lack of understanding or insufficient experience in the need for compressor flows to be absent of particles (both solid and liquid). Mechanical engineers are keen on gas streams free of particles both solid and liquid but the system design has been set by the chemical engineers who lack experience in mechanical details. So the finger pointing exercise begins about who is responsible for compressor failures. So let's set a design standard which will provide long compressor life:

The knockout drum system must be capable of handling:

**a)** 1.25 to 1.5 times the process flow with minimum of 5 minutes residence time at highest flow rates (this allows big particles to settle from the gas stream),

**b)** slug flow for at least 5 seconds where the line is filled with fluid at 1.25 to 1.5 times the process flow (this allows for handling slug flow abuses and upsets),

**c)** 99% of all particle sizes (liquid or solids) greater than 3-5 microns must be removed before reaching the compressor and the dust load must be less than 40 $mg/m^3$ (this protects the compressor for achieving long life free of failures—called reliability).í

í Some particle size exceptions exist where, on purpose, flush materials such as water or naptha are purposely injected into compressors to mechanically dislodge deposits on the first-stage compressor.

The injected material never exceeds 2 to 3% (absolutely maximum) by weight (not by volume). 60% (of the maximum 3%) goes into the first-stage intake nozzle and the remaining 40% (of the maximum 3%) goes into return bends of the diffuser.

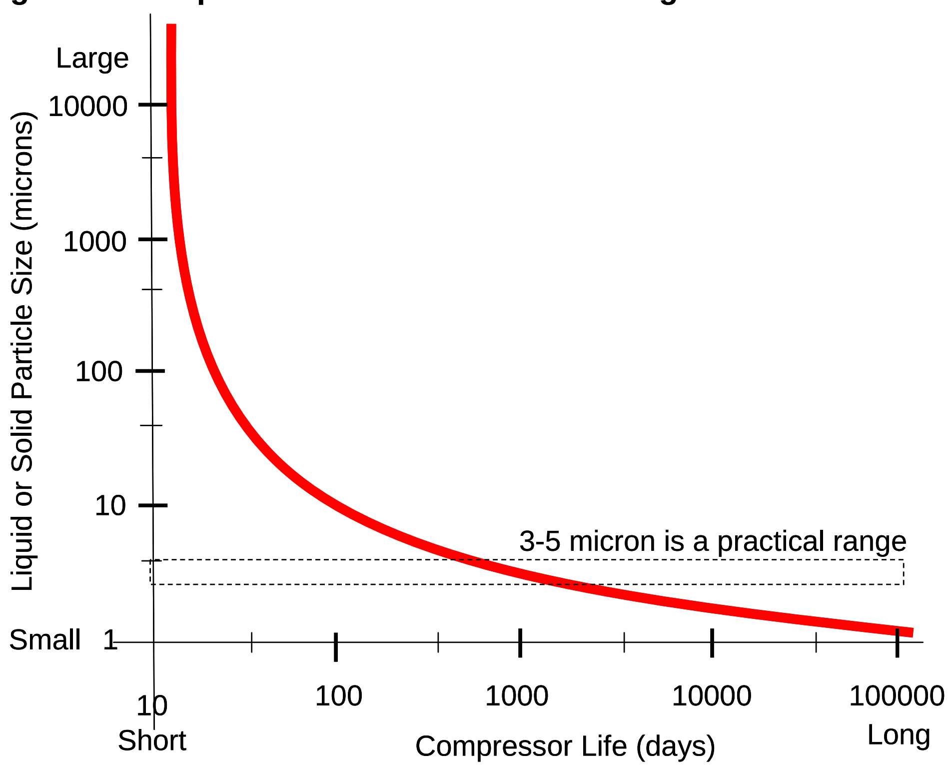
The carefully and finely atomized fluids for dislodging deposits on the compressor will, on purpose, exceed 5 microns to achieve mechanical dislodgement of deposits. The coarse particle size fluid flush does not (as often inferred) chemically dissolve deposits.

Items a) and b) are of direct interest for chemical engineers.  Item c) must be planned and sized by chemical engineers to protect the interest of mechanical engineers responsible for long, failure free life of rotating equipment.

Cost of the properly specified and designed knockout drums incurs a one time capital expenditure. However, failure of item c) is an ongoing expense which disrupts production and incurs the high cost of lost profit opportunities which will recur many times during the life of the compressor from the **silent root cause** for failure.

The rough general relationship between particle sizes and equipment life is shown in Figure 1 (of course individual compressor components make this trendline very broad).

**Figure 1: Compressor Life vs Particle Size Ingested**



A compressor can ingest an occasional large particle. It cannot sustain a torrent of large particles. Some relationships between ingested particle sizes and life have existed for many years. For example, the life of an automobile internal combustion engine is ended after ingesting only one tablespoon of dust/dirt! Bloch's book on Reciprocating Compressors on page 150-152 list four categories for foreign materials that kill compressors and give clues of what to look for:

1. **Liquid carryover**
   (slug flow, carryover from interstage coolers, flow changes)

2. **Dirty gas**
   (solid particles act as grinding compounds and interference debris)

3. **Carbon formation**
   (high temperatures, oils, and gases make carbonaceous debris)

4. **Corrosive elements**
   (corrosion, erosion, and complex failure modes occur)

The hierarchy of simple to complicated devices for cleaning gas streams is:

1. Parallel corrugated plates are knockdown devices to eliminate large particles such as sand.

2. Filters and bag houses remove solid particles.

3. Cyclones are ~90% efficient for 40 micron particles or larger.

4. Knockout drums, without demisters, are ~90% efficient for 600 micron particles or larger (these are OK for flare knockout drums but not for compressors).

5. Knockout drums with cyclone(s) build inside the drum will help eliminate fluids and solid particles ~90% efficient for 40 micron particles or larger.

6. Knockout drums with thick and clean demister packs are ~98% efficient for droplets/particles larger than 20 microns.

7. Helical coil gas flow separators remove 99.9% of all solids and liquid particles 6 microns or greater which includes black powders occurring in natural gas pipelines from the reaction of $H_2S$, water, and iron in the pipe.

8. Coalescing filters handle liquids and solids with ~95% efficiency for droplets larger than 0.5 microns.

9. Electrostatic filters are good, but never as good as advertised, in eliminating small particles because of maintenance difficulties of

washing/cleaning.

10. Polymer membranes are coming on strong for selective removal of all size particles and for selective removal of different fluids including separation of gases.

My experience says the <u>**silent root cause**</u> killer reasons for compressor failures are one or more of the following reasons:

Insufficient knockout capability in the original design without allowance for a 1.25 to 1.5 safety factor. This safety factor is consumed when flow stream creep occurs to overload the knockout drum.

1. Design failures when knockout capability is based on <u>average flow</u> rather than <u>peak flow</u> and without calculations for slug flow capability. Think of the newspaper headlines used in a well known statistics class to emphasize the huge differences between the average and the extremes:

   "**Man Drowns In River Of 6-Inches [15 cm] Average Depth.**"

   You don't drown on the averages; you drown in the deep spots of a river! You don't usually kill a compressor on the averages but extremes are dangerous as they transfer the particle size problem down stream to become a compressor failure from fluid particles/slug flow/solid particles in the flow stream.

2. Design failure to eliminating dirt/moisture particle sizes greater than 0.5 to 0.3 microns at 95 to 99% efficiency. **This is a stringent design criterion that would stop many compressor failures**.

3. Design capability for flow surge must be provided for handling occasional slug flow based on full line flow of liquids for at least 5 seconds or longer periods of slug flow based on knowledge of the peak problems.

4. A common urban myth fallacy is that knockout drums are believed to be such simple designs a draftsman can size them. This myth will guarantee downstream problems for the compressor.

5. Another urban myth is to purposely heat the process gas so you don't have moisture particles in the gas in lieu of other solutions. True, liquid particles can be vaporized. However, high temperatures add severe service onto the compressors, and with limited long term success on highly loaded and sophisticated compressors. This heating technique is also reported downstream of knockout drums and coalescing filters. The best solution is to eliminate the liquid/solid particle problem at the source rather than generating a secondary problem of higher heat in the compressor.

6. A design flaw of ONLY using the Souders-Brown equation considers vapor velocity but **NOT** particle size (see #3 and 4 above). Remember, the design requirement for knockout drums is an **AND** solution for **both** flow <u>and</u> escaping particle size, i.e., don't exceed the design flow and

don't exceed the maximum particle size. Chemical engineers, in most cases, are only concerned with the average separation of liquids from the inlet stream, but mechanical engineers are concerned with the particle sizes and content of the particles in the gas stream which kills the compressors. We need teamwork for achieving the investors **lowest long term cost of ownership**. (Yes, the issue is similar to the comment that the heart doctor doesn't want you to die from a heart attack but you may die from kidney failure from the medicine he gives you for your heart.)

7. Another urban myth is emergency relief flare systems and compressors have the same requirements for knockout drums. **This is not true.** Flare systems have are far less stringent requirements (meaning they can handle larger particle sizes, 300 micron). Compressors have more severe requirements than flare systems!!

Compressor genocide is practiced regularly in industry. To prevent compressor genocide you must attack **both** the particle size and the flow rate issues including provisions for slug flow. This infers different stages of separation using some or all of steps 1-10 noted above. Remember there are some cases where knockout drums, demisters, and coalescing filters still have problems as described at the Naval Air Station Lemoore. However, compressor manufactures also stress the need for different stages of separation even for reciprocating compressors to provide gas inlet filtering, liquid removal and liquid coalescing systems upstream of the compressors.

Don't be fooled. Your compressor failure problems may simply be due to an up-stream problem with knockout drums (and associated equipment to remove particles from the flow stream).

Heavily loaded compressors and sophisticated compressors have less tolerance for handle insults from surges and particle sizes.

Treat your compressors like race horses. **DO NOT** treat compressors like plug horses if you want to achieve high reliability with long life between failures.

Remember, many compressor failures are self-induced failures. The **silent root cause** for many compressor failure stem from knockout drums and other associated equipment for liquid and solid removal.

Knockout drum design has to be done correctly from the beginning. It's too expensive to make corrections after the error(s) has been proven. Furthermore in most facilities, no additional space is available at a later date for installation of the correctly sized and designed knockout equipment.

**Further reading-**

Amistco has a good paper on knockout drums including use of a cyclone to knock down liquids (and solid particles) before reaching demister pads and their double pocket vane units. They also provide some design details including why you should anticipate sudden flow changes in both directions. Amistco includes retrofit solutions for existing designs.

Helical coil separators from Mueller Environmental remove fluids, solids, and slug flow from gas streams including pyrophoric black powder sulfides in pipelines with 99.9% efficiencies down to 6 microns which depends upon high velocity gas flows to achieve the efficiency.

Coalescing filters allow small droplets in the gas stream to collide to continuously enlarge as additional droplets collide and finally collect as they move downward by gravity into the liquid collection system. They can be glass/plastic, fine mesh knitted screens for large particles, or sintered metal for small particles.

King Tool produces a self-cleaning, mist coalescing filter while the filter remains on line. The system periodically has a reverse flow to each coalescing filter element to self-clean selected elements without a shutdown. The reverse flow cleaning extends filter life by a factor of 20-50 while trapping solid particles smaller than one micron. Trapping and removal of very small particles is helpful for removal of iron sulfide particles from sour gas pipelines whereby the particles are flushed out in the liquid with minimal re-entrainment.

Separation of amine from fuel gas is reported as a critical element in elimination of burner tip fouling which requires the use of coalescing filter devices as reported in NPRA Q&A's from 1997 and 2000. Coalescing filters are very sensitive to flooding from too much fluid, and efficiency drops rapidly when challenged with too much liquid whereby liquid re-entrainment occurs as shown in the Pall report of Figure 4. **This means you need to oversize the capability for coalescing filters and do not undersize the coalescing filters to achieve long term success.**

Other good design criteria are provided by the Iranian Ministry of Petroleum for in Gas(Vapor)-Liquid_Separation and API Spec 12J ( search for the 25 page spec and the price is US$94) for oil and gas separators as devices located on the producing flow line between the wellhead and pipeline.   Routinely, slug flow beyond the knockout drums are equipment killers.

The G(V)-L Separation document calls for 2 to 5 seconds of normal feed velocity at 100% liquid filling of the feed pipe.  Most folks go blind at the slug flow requirements.  They ignore surges.  The designers may have forgotten the surge requirement, but slug flow kills the compressors, and damage due to the slug flow is cumulative on the compressors (it's not just a one time event).

Many knockout drums have the demisters pads blown-out due to surges.  The result of blown-out demister pads allows 150 to 2000 micron size particles moving downstream to the compressor as equipment killers.  With demisters pads in place, the particle sizes moving downstream may be 10 microns which are still too large for highly loaded and sophisticated compressors to handle without damage.

The use of nanomaterials in coalescing filtration is described in the WIPOA.

OK, so this is more than you wanted to know about knockout drums, coalescing filters, etc.  I've gathered these details to avoid the compressor Achilles heel problem with chemical engineers designing knockout drums which are incapable of handling slug flow as they satisfying their need for filling a space on a PDF.

**BUT** lack of teamwork and lack of understanding sets-up the mechanical engineers for failure on their compressors because too many large particles (solid/liquid) are passed along to kill the expensive rotating equipment for which chemical engineers have ~zero appreciation for how susceptible compressors are to abuses of slug flow and too many large particles entrained in the gas flows.

**Where would you look for reference materials—**

Look in Perry's Chemical Engineers' Handbook, 8$^{th}$ edition for knockout drums and you'll find nothing in the index.  However, if you look in Section 6, Fluid and Particle Dynamics you'll find some details about falling liquid drops in gases.  Section 10 pertains to Transport and Storage of Fluids, Section 17 pertains to Gas-Solid Operations and Equipment, and Section 18 pertains to Liquid-Solid Operations and Equipment—none of them address knockout drums.  The single reference the chemical engineer would touch first is of no help for knockout drums.

Ludwig's Applied Process Design for Chemical and Petrochemical Plants, 4th edition is more helpful with 72 pages of illustrations and calculations for mechanical separations involving:

1) liquid particles from vapor or gas,
2) liquid particles from immiscible liquid,
3) dust or solid particles from vapor or gas,
4) solid particles from liquid, and
5) solid particles from other solids.

In none of the chemical engineering separator cases does a design limit exist for size of particle going into compressors [thus the criterion specified above to satisfy both chemical engineers and mechanical engineers to solve expensive failure problems together]. Of course the particle size concept is implied by the class or grade of the separation techniques but it is never clearly spoken for understanding by both chemical and mechanical engineers. **Take heed: Figure 1 above defines a valuable criterion—in short, limit the size of particles going into a compressor!**

**Some Final Words-**

All separation systems are made for selling. Some separation systems are made for use with your compressors to achieve long life with few failures.

Don't get caught in the leap of faith with sweet sounding words by good salesmen. Use your head about what you want and need.

Be skeptical with show me, don't tell me the results to achieve long compressor life with few failures.

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