Case Study: Root Cause on Seal Failure in Refinery

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Many different factors contribute towards the failure of a pump. Some factors that did not seem to have contributed to earlier failures were not examined or considered and may become the cause of failure under other situations. Failures do not occur suddenly. Usually there are many symptoms, which signal a failure situation and are generally termed as potential failure modes. The ignorance of such symptoms almost always leads to failure.

Below are two case studies pertaining to mechanical seal systems, a vital component of pumps operating in running process plant.

Case A: Even a standby pump can have a seal failure, and a hazard associated with it

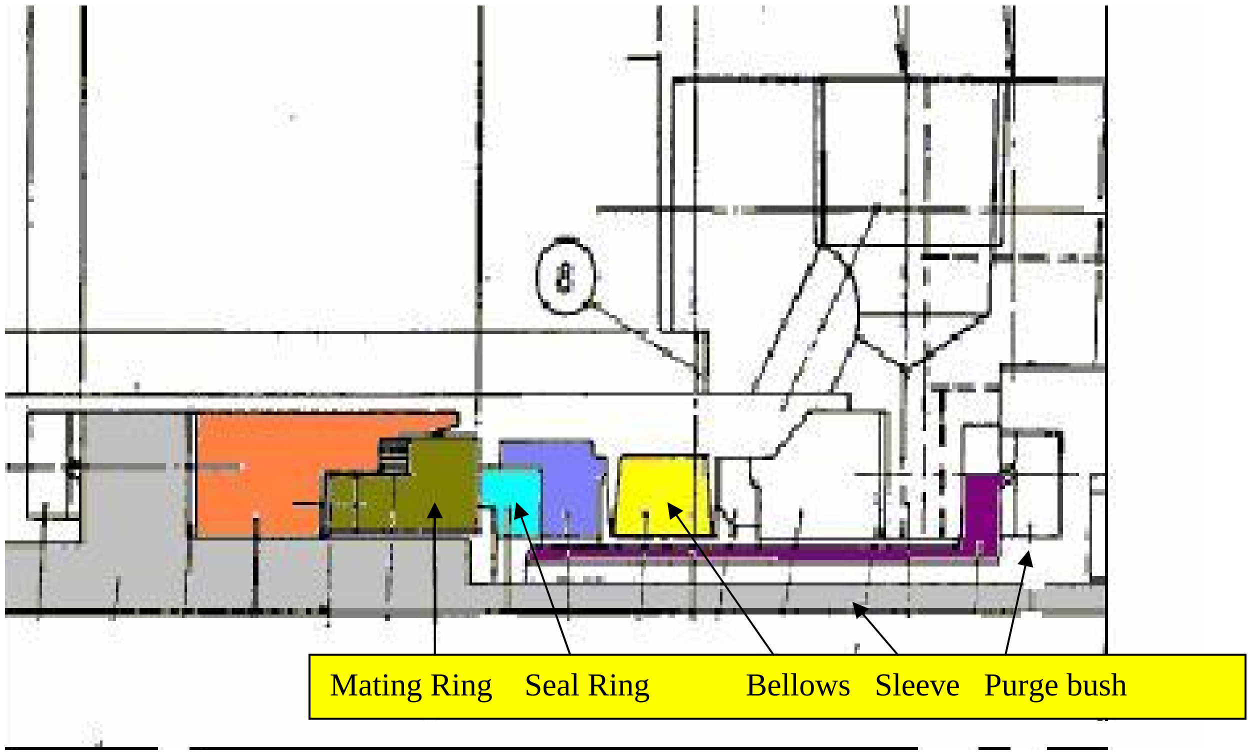
We have come across many instances of seal failure or hazard due to seal failure of running pumps, especially in light hydrocarbon or high temperature hydrocarbon services, but the fire hazard due to seal failure of idle pump is a rare event and unpredictable.

Pump type and operating parameters: single-stage centrifugal back pullout design, made by Thomson-Byrton. Flanges: 300# 4” suction, 3” discharge. Impeller has balancing holes.

Service: Jute Blending (JPB), 2900 RPM, 310 0C, 89.4 m^3/hr flow, 90.8 m head, 0.67 specific gravity. Suction pressure 1.5 Kg/cm^2 (gage units), V.P. @ P.T. (vapour pressure at pumping temperature) is 1.0 Kg/cm^2 . Minimum flow (MCSF) is specified by manufacturer as 22.7 m^3/hr

Mechanical parameters: bearings 6311C3/7310; bellows seal with flush plan 02 and 62; cooling plan G. Material of major parts: 410ss, 316ss, CS. Lubrication type: oil lubrication with Turbinol-68

This pump did not have on-line monitoring, and thus no alarm or trip signals available.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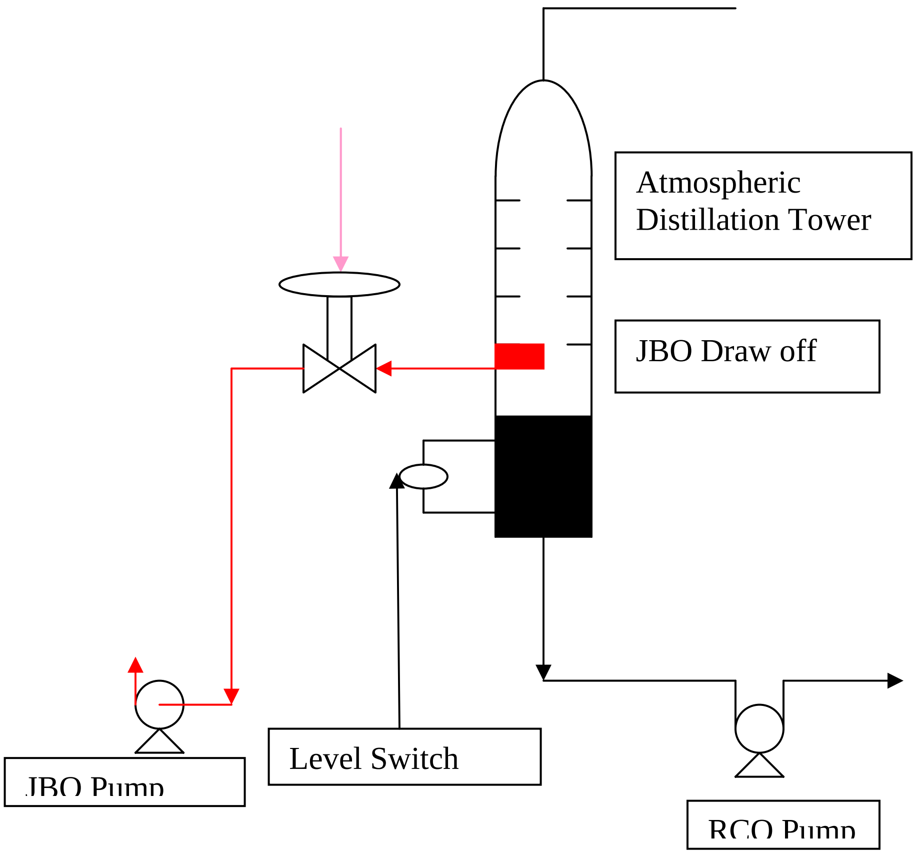
Mating Ring
Seal Ring
Bellows
Sleeve
Purge bush

Description of the initial problem

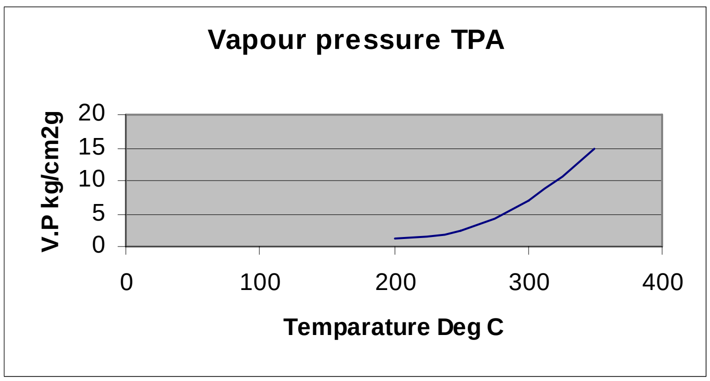
Two pumps are connected to the distillation tower. They are referred to as RCO (Reduced Crude Oil) pump and a JBO (the one described here) pump. Due to process yield requirements, the JBO pump operates at 17 m^3/hr, which is below the minimum flow requirement of 22 m^3/hr. In case the tank level drops below a certain value, the JBO draw-off control valve begins to close to raise the fluid level which is critical to RCO pump. Unfortunately, this causes problem for the JBO pump, which goes to cavitation leading to subsequent component failures under cavitation.



The JBO pump is fitted with single stationery bellow seal having face combination carbon vs. silicon carbide and initially the flushing plan was 02/62. The seal used to fail ("smoked") very often indicating inadequate seal face cooling and twice seal failed under situation of starvation. This became highly alarming as the seal failure caused fire due to flashing of hot product in to atmosphere.

To curb the recurrence of such incident two immediate measures were taken:

- Installed recirculation line
- Provided external flushing Plan 32 with TPA media fluid (V.P 1.3 kg/cm^2 (gage) at 200 ^{0}C) at actual pressure of 4.5 kg/cm^2 at 150 ^{0}C was provided. Seal box pressure was 3.2 kg/cm^2



At first, this modification of system appeared to have solved the problem, ***but again there was a seal blow-off event after three months***.

Surprisingly, this time it occurred to hot standby pump. Hot stand by means primed idle pump with discharge valve partially open condition and the fluid recycling through warm up line by thermal convection, to keep the pump ready for start in case failure of running one.

On investigation it was noticed that external flush to seal box of stand by pump was stopped earlier to facilitate adequate flush to running pump seal following a pressure drop in external flush media system. The seal blown off while the operator re-opened the seal flush line after two days to put the subject pump back in service as per routine changeover schedule.

Analysis

During suspension of external flush TPA flow, the line content got cooled off due to stagnation within the bare pipeline. The seal box pressure of hot stand by pump was nearly equal to suction pressure, i.e. 1.5 kg/cm^2 (gage). Subsequently while recommissioning the external flush flow again to the seal box containing service liquid at above 300 ^{0}C , the cold TPA has a fast temperature rise, with a problem at a pressure much lower than its corresponding vapour pressure (V.P of TPA at 300 ^{0}C is 7 kg/cm^2 gage).

This had resulted rapid vaporization at seal box and on seal faces as well causing opening of seal faces due to sudden pressure rise and the hot JBO flashed in to atmosphere causing minor fire.

Action Taken

It was decided and advised to operation crews that the external flush flow must be kept ON even the pump is standby. In case an emergency requires to stop the external flush flow, the pump must be isolated from the system closing its suction, discharge, warm-up lines etc.

The external flush media source changed to a dedicated system having separate pumps and source for flush. While recommissioning, the external flush to be established before opening the suction valve for priming.

Case 2: Seal Failure of RCO Pump

Service – Reduced Crude Oil
Unit - Fuels Refinery Expansion
Make- M/S Arai JAPAN
Year of Commission - 1999
Type - Two stage. Reverse suction, centerline-mounted between-bearing centrifugal pump.

Process Parameters:
Flow: 127 m^3/hr
Sp.Gr: 0.7
Process Temperature: 352 Deg C
V.P at P.T: 1.5 kg/cm^2 gage
Minimum Flow: 4 m^3/hr
Suction Pressure: 1.8 kg/cm2 gage
Discharge Pressure: 29.5kg/cm2 gage
NPSHa: 2 meters
NPSHr: 1.8 meters

Mechanical Parameters:
Radial Bearing- 6311C3 (DE)
Thrust Bearing - 6309C3 (double row) (NDE)
Shaft sealing – Mechanical seal rotary bellows, Carbon/SC, cartridge type
Flushing Plan –32 (external seal oil)
Cooling Plan –G

Stuffing box Pressure: drive end 1.8 kg/cm2 gage, opposite end 13.0 kg/cm2 gage
Materials of construction (MOC) of major parts: shaft SS410, impeller CF8M, wear parts-SS316, casing and bearing housing- cast steel.

Previous failure history (before introduction of plan-32):
The dedicated external seal oil system for the RCO pumps was commissioned in January, 2003. Initially this pump was having flushing plan 22/62 (flushing from pump discharge through strainer, cooler and orifice to seal) with steam quenching.

MTBF of seal prior to introduction of Plan 3 was 8 months.

The initial flush plan 22 was not effective due to plugging up of cooler and associated piping, especially while pump used to be standby leading to non-availability of pump as hot standby. Subsequent to this plan 02/62 was also tried but it did not improve the situation significantly: seal continued to "smoke" and covered with coke formation. Ultimately it was decided to provide external flush (virgin gas oil) through a dedicated seal oil system to avoid smoking of seal and adequate seal face cooling, to prevent coke formation and seal leakage.

Incident

The external flush was introduced through orifice of size calculated based on the differential pressure between the flush media pressure (16 kg/cm2 gage) and individual seal box pressure with due consideration to required flow (5 to 6 lit/min).

Few days after commissioning the system the seal leak reported again, although not as a fire hazard due to presence of the external flush as barrier fluid. It was observed the bellows got punctured and uneven wear track on seal faces. The runout of shaft portion exposed for seal and the gland plate pilot surface trueness were checked with no noticeable deviations observed. Following this seal assembled with new bellows and the pump was put back to service.

The seal leakage started within few hours of operation of the pump.

Observations after dismantling the seal:
1 - Bellows found ruptured.
2 -The seal mating face wear pattern was not concentric.
3 - Both the faces were good.
4 - Thrust bearing was good and intact.
5 - Secondary packing was good and intact.

Suspected causes:

Shaft deflection due to piping stress, unbalance rotor, hydraulic unbalance
Out-of-perpendicularity of shaft with respect to stuffing box face
Low pressure limit of bellows.

<u>Analysis</u>:
As all process parameters and rotor dynamics symptoms were normal and both the bearings were good and intact, the possibilities of shaft deflection due to hydraulics / rotor dynamics were ruled out.

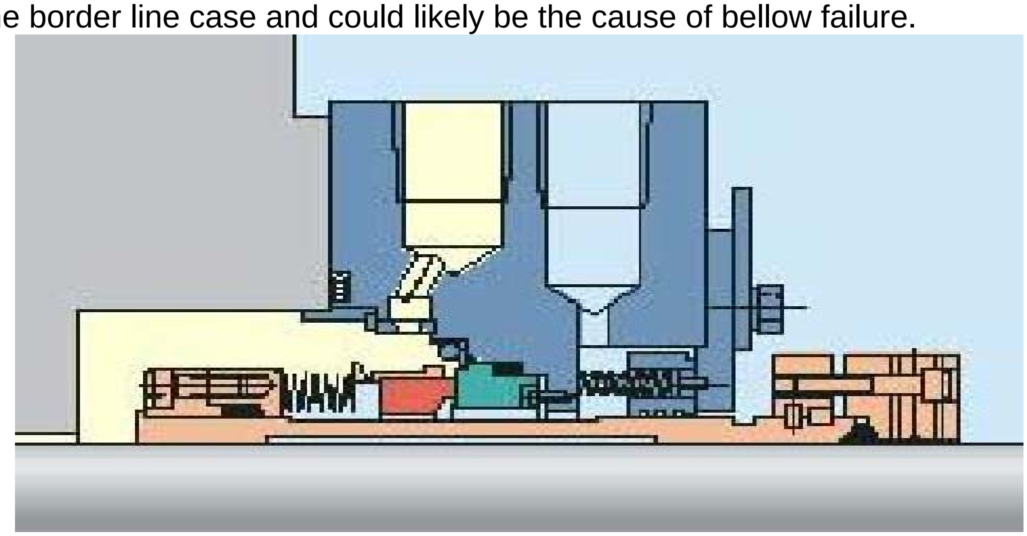
As a standard procedure, stuffing box, casing & bearing housing bore and faces are machined & maintained concentric and perpendicular with respect to shaft by the pump manufacture and after machining; all these parts are assembled with proper trueness with help of piloting steps or dowel pin each to avoid the problem of eccentricity and out of perpendicularity. During subsequent dismantling/assembly by user at time of repair/overhauling the factory set dowels/piloting steps act as reference guides to ensure concentric/perpendicular assembly of stationery parts with respect to rotor assembly.

The maintenance practice does not specify the checking of concentricity/perpendicularity, as a regular activity which is only done in case any symptom of eccentricity is noticed. It is to be noted that same seal never displayed this type of failure mode prior to introduction of high pressure external seal flush.

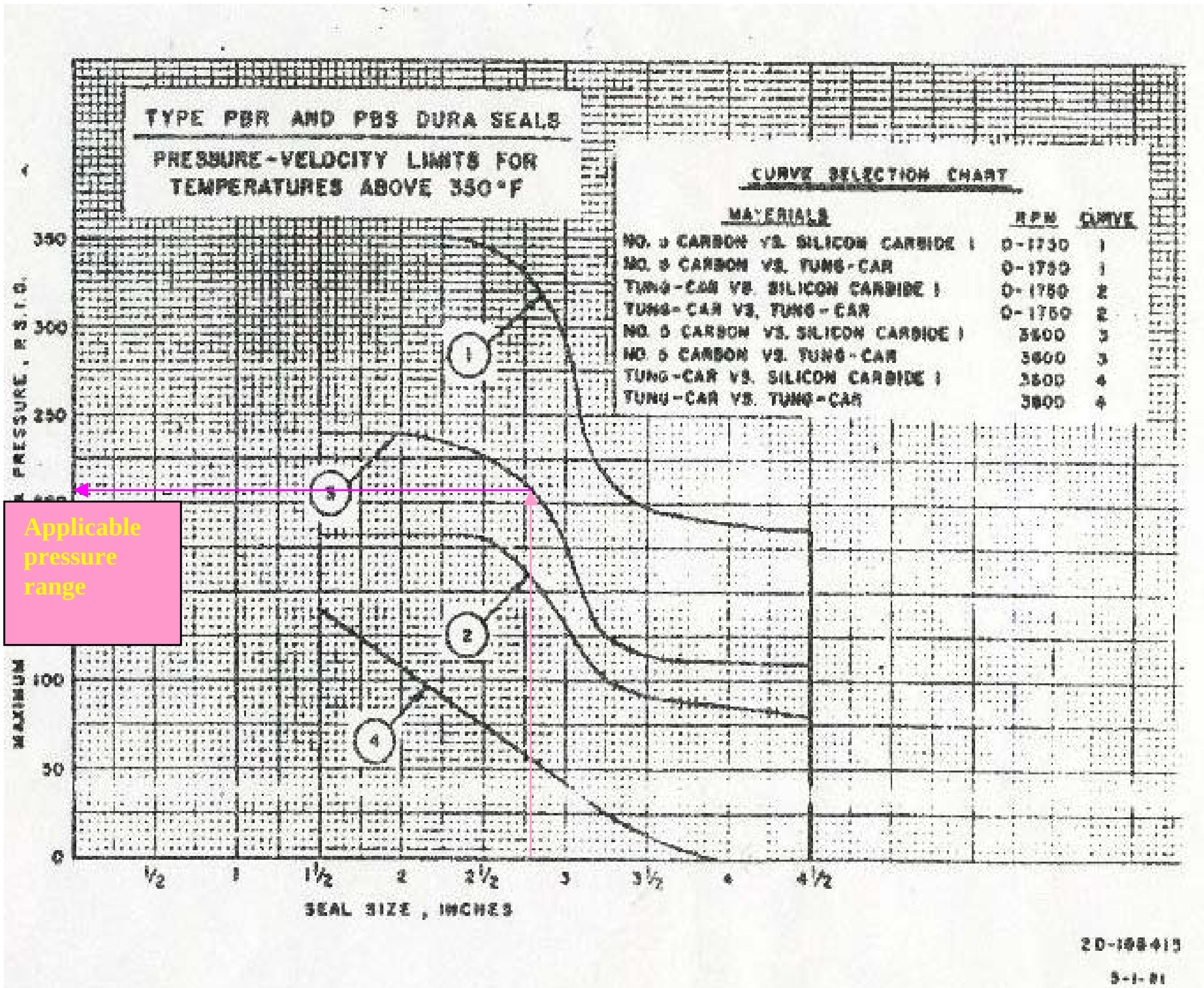
Parameters changed after introduction of plan 32 were:

1. Stuffing box pressure at NDE increased form 14 bar to 17 bar.

As per the seal vendor spec, the max pressure limit for bellows is 15 bar, which is the border line case and could likely be the cause of bellow failure.



Seal: 2.750" Single PBR Cartridge Seal Make: FlowServe Sanmar



2. The pressure limit of PBR seal (4mils bellows AM350 ply thickness) as per the PV graph is 15 bar. The bellows did not develop this type of failure when the flushing Plans were 02/62 and the stuffing box pressures were around 14 bar. When the API Plan was changed to 32, the stuffing box pressures increased to 17-18 bar. As the Plan 32 pressure is more than the seal pressure allowable limit, it could cause over pressurization of the seal and eventually the seal will fail.

Immediate actions: Recommended to change the bellows assembly material to Inconel with a bellows thickness of 8 mils to withstand higher pressure. The bellows mounting changed to stationery type from rotary type. Thus the rotor dynamics (due to torsion) loads and fatigue loads even in presence of any concentricity problem, will not affect the bellow stability.