# Process Plant and Equipment UP-TIME

**The basic engineering maintainers and operators need to keep plant reliability up and operating costs down.**

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# CONTENTS



## Process control talk

## Changing the Service Duty of a Pump

**What readers will learn in this article.**

- Centrifugal pumps can be moved to a new service.
- The impeller size, impeller speed and motor power need to match the new service.
- That Similarity Law formula is used in calculating the new impeller size, speed and motor power.
- Introduction to centrifugal pump curves and their use.

When there is a need to determine a new service duty for a centrifugal pump, and no performance curves are available, the recommended method is to use the Similarity Laws. These laws are derived by the use of dimensional analysis in which selected variables affecting performance are grouped in such a way that permit prediction of scaling effects when the variables are altered. The laws are:

$$\frac{Q_1}{Q_2} = \frac{N_1 D_1^3}{N_2 D_2^3} \qquad \frac{H_1}{H_2} = \frac{N_1^2 D_1^2}{N_2^2 D_2^2} \qquad \frac{P_1}{P_2} = \frac{\rho_1 N_1^3 D_1^5}{\rho_2 N_2^3 D_2^5}$$

Where: Q is discharge flow in l/sec.
D is impeller diameter in mm.
$\rho$ is density in kg/m$^3$.
N is impeller speed in rpm.
H is discharge head in meters.
Subscripts 1 and 2 represent initial and final conditions respectively.

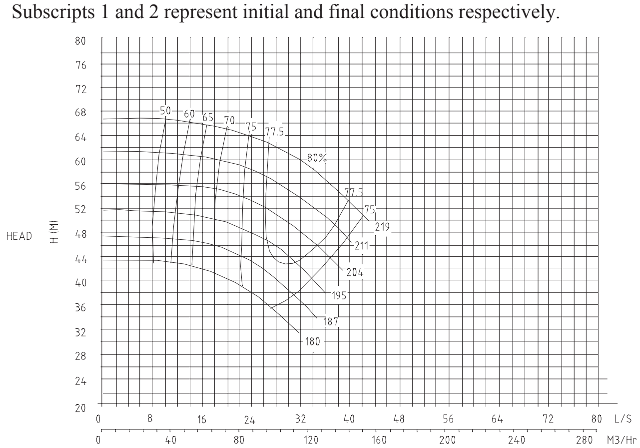


Figure 1 Set of pump curves

If in the equations above, the impeller diameter is held constant and the density is unchanged, the formulas reduce to the well-known Affinity Laws.

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \qquad \frac{H_1}{H_2} = \frac{N_1^2}{N_2^2} \qquad \frac{P_1}{P_2} = \frac{N_1^3}{N_2^3}$$

The users of these laws put a lot of faith in their ability to predict the required changes to a pump to achieve a new duty. Once the pump is altered it is costly to reverse. But how accurate are these formulas? To determine this, they are used to establish a new duty point for a centrifugal pump pumping water and the result compared to the published pump curves. The difference between the curves and the laws is then observable.

The calculations are for a commonly encountered situation where a pump's delivery head is to be reduced. In this case the impeller will require machining to a smaller diameter. The pump has an existing duty of 24 l/sec at 64m head with an impeller of diameter 219 mm. If the impeller diameter is reduced to 195 mm what is the new duty point calculated by the Similarity Laws? The applicable curves for the 219 mm and 195 mm impellers are shown on Figure 1.

Changing impeller size affects both the pump discharge head and the flow. This requires use of the Similarity Laws to calculate both the new head and the new flow.

| START POINT | CALCULATED POINT | CURVE POINT | PERCENT DIFF. |
|---|---|---|---|
| $Q_1$ = 24 l/sec<br>$H_1$ = 64 m<br>$D_1$ = 219 mm<br>$N_1$ = 2900 rpm | $Q_2$ = 16.9/sec<br>$H_2$ = 50.7 m<br>$D_2$ = 195 mm<br>$N_2$ = 2900 rpm | $Q_2$ = 17/sec<br>$H_2$ = 50.7 m<br>$D_2$ = 195 mm<br>$N_2$ = 2900 rpm | negligible<br>negligible |

If instead the impeller diameter is reduced to 180 mm we get the following results.

| START POINT | CALCULATED POINT | CURVE POINT | PERCENT DIFF. |
|---|---|---|---|
| $Q_1$ = 24 l/sec<br>$H_1$ = 64 m<br>$D_1$ = 219 mm<br>$N_1$ = 2900 rpm | $Q_2$ = 13.3 l/sec<br>$H_2$ = 43.2 m<br>$D_2$ = 165 mm<br>$N_2$ = 2900 rpm | $Q_2$ = 13.3 l/sec<br>$H_2$ = 42.8 m<br>$D_2$ = 165 mm<br>$N_2$ = 2900 rpm | negligible<br>1 |

From the results of the calculations it is clear that for this manufacturer's pump the error in using the Similarity Laws is minor though it becomes larger the further the required duty point is from the existing duty point. These results provide some confidence in the use of the formulas. However when the same method was used for another manufacturer's pumps a discrepancy between the similarity laws and the pump curves of up to 7 percent was noted. The results are not always exact.

In situations where it is necessary to machine the impeller diameter down it is sensible to leave the impeller larger than calculated and reinstall it. Then establish the intermediate duty point and again calculate what impeller reduction is needed to attain the final required duty point.

For the alternate situation where a higher delivered head or flow is required, the Similarity Laws can be used to estimate the new faster impeller speed or to size a new larger impeller. When increasing the speed or the diameter of an impeller a higher head, flow and power draw result. The appropriate Similarity Law will provide a means to closely estimate the extent of the resulting change.

*Mike Sondalini - Maintenance Engineer*

# Open trickle chutes for damp bulk product.

**<u>What readers will learn in this article.</u>**

- The flow of bulk materials through chutes is affected by internal properties of the bulk product.
- Friction exists between the chute walls and a moving product.
- Momentum and velocity must be maintained when running bulk materials through chutes.
- Bulk materials chute design and use considerations.

For the effective flow of a cohesive (sticks to itself) product, a chute must be designed to maintain momentum & velocity.

Flow in an open chute is the result of the interaction between gravitational and frictional forces. Open chutes block because frictional forces between the product-to-chute surface or product-to-product contact have overcome the momentum produced by gravity (unless a foreign body is stuck in the chute). This momentum is reduced through friction and adhesion.

Friction effects are reduced by fabricating from materials of low friction coefficient and minimising the surface area in contact with the flowing material while not causing bridging. Adhesion is reduced by using steep inclinations, introducing gradual direction changes in the chute and by providing a period of free fall into the chute to allow velocity to develop. By minimising friction and adhesion from product contact with the wall, the material is able to retain its velocity and momentum to continue its motion.

An example of applying some of the above ideas was in the redesign of an open inlet chute into a gas fired rotary drier. The products fed to the drier were damp and cohesive with a tendency to adhere to the chute walls. Product flow rates varied from 2 tonne per hour of wet fertiliser granules to 20 tonne per hour of moist ferrous sulphate.

The original 2.5m long chute was made of 3 mm steel sheet with a 400 mm wide base, 300 mm deep sides and no top. The metal had rusted and had been bashed and hammered in attempts to clear blockages. It was inclined at 70 degrees with a bend half way down where the incline changed to 40 degrees so as to feed the product further into the drier.

Product built up in the chute at the bend and necessitated regular cleaning of the blockages.

The redesign involved a change to the material of construction and removal of the bend midway down to make the chute straight. It required installing helical fights in the drier to insure product, which now fell into the drier further back than previously, was fed forward and did not accumulate at the entrance of the drier.

The entire chute was made of 316 stainless steel with the intention that it would stay smoother because it would not rust. Plastic liners could not be used as heat from the drier escaped out the chute. The angle of the chute was retained at 70 degrees and the chute walls past the location of the old bend were increased to 400 mm high in order to prevent the product leaving the chute until the exit. The other dimensions remained unchanged.

Following the changes the products did flow better through the chute. However in the case of the wet materials they first hit the chute bottom heavily and squashed firmly against it. Fortunately these materials heaped up in a fashion which created their own incline and once the incline was established the products rolled off themselves into the chute.

The use of a wide chute allowed the various materials to flow mainly along the chute bottom and not contact the side walls simultaneously. This limited the friction effect by minimising the area of product-to-surface contact and helped maintain the flow velocity.

Over a period of days and various product changes, the walls and base of the chute became coated in built-up material from the accumulated splatter of product as it flowed through the chute. Though the build-up was thick it did not stop product flow. Provided the product developed sufficient momentum it continued to move down the chute. The presence of the splattered product negated the benefit of using stainless sheeting and confirmed the importance of designing chutes with sufficient incline to produce flow.

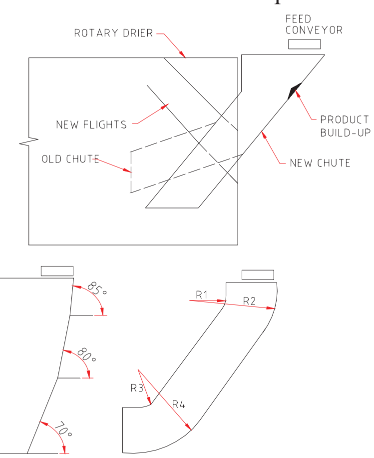


Figure No. 1 Trickle Chute Design Options

Figure No. 1 shows a sketch of the installation along with sketches of other possible solutions to the problem.

*Mike Sondalini – Maintenance Engineer*

# Protecting bearings from dust.

**<u>What readers will learn in this article.</u>**

- Bearings in dusty environments require added protection against dust ingress.
- The use of shaft seals and how they protect bearings.
- Eight dust ingress control methods for bearings.
- Good contamination reduction practices when assembling bearings and parts.

Dusty surroundings are one of the most difficult environments for bearings. In equipment handling powders or in processes generating dust the protection of bearings against contamination by fine particles requires special consideration.

**<u>Bearing Housings</u>**

Bearings are contained within a housing from which a shaft extends. The shaft entry into the housing offers opportunity for dust (and moisture) to enter the bearing. The shaft seal performs sealing of the gap between the housing and shaft. Choice of the appropriate shaft seal and seal configurations to protect against dust ingress is critical.

Bearing housing seals for dusty environments may be either a labyrinth type or a rubbing seal type. The labyrinth type requires a straight shaft running true. Rubbing seals are the more common and allow for some flexing of the shaft. Figure No. 1 shows conceptual examples of each type of seal. When setting a lip seal into place to prevent dust ingress insure the sealing lip faces outward.

In situations of high dust contamination there may be a need to redesign the shaft seal arrangement for better dust protection than provided in standard housings. Some ideas, which can reduce dust ingress into bearing housings, are to:

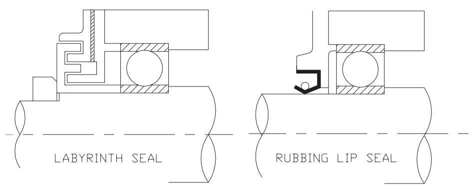


Figure No. 1. Shaft Bearing Housing Seals

i. provide two or more seals in parallel. Bearing housings can usually be purchased with combination seals as standard.
ii. retain the housing shaft seals but change from a greased bearing in the housing to one which is sealed and greased for life. If contamination were to get past the shaft seals, the bearing's internal seals would protect it.

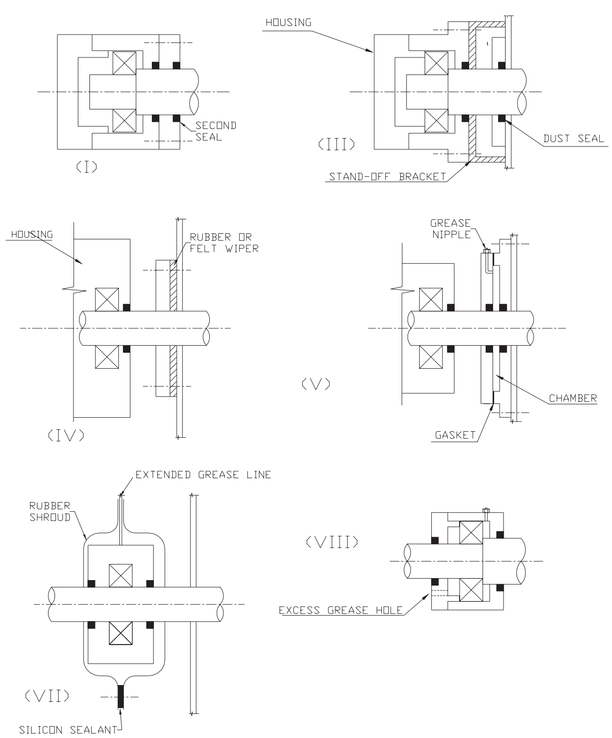


Figure No 2. Conceptual Sketches of Dust Sealing Methods

iii. stand the bearing off the equipment to create a gap between the end of the equipment and the bearing housing while sealing the shaft at the equipment.
iv. put in a felt seal wipe between the housing and the wall of the equipment to rub the shaft clean. Install of a mechanical seal in very harsh environments.
v. install a grease barrier chamber sandwiched between two seals. This barrier is separate to the bearing housing and acts as the primary seal for the bearing. Grease pumped into the chamber will flush out past the seals.
vi. replace the grease barrier chamber instead with an air pressurised chamber.
vii. shield the bearing housing from dust with use of a fabricated rubber shroud encapsulating the housing and wiping the shaft or fit a rubber screen with a hole wiping the shaft over the opening emitting the dust.
viii. flush the bearing with grease by pumping excess grease into the housing and allowing the grease to be forced past the shaft seals or through a purposely drilled 15 mm hole in the housing. The hole must be on the opposite side of the bearing to the grease nipple, at the bottom of the bearing housing when in service and between the bearing and seal.
ix. Mechanical seals can be fitted to the shaft with the stationary seal sitting toward the machine and the rotating seal mounted back along the shaft. Combinations of other seals and wipers can also be used in combination with the mechanical seal.

Some conceptual examples are shown in Figure No. 2.

**ASSEMBLY**

The process of assembling a bearing into the housing must be spotlessly clean. If contamination occurs at the time the housing is assembled no amount of external protection will stop the bearing from premature failure. When assembling bearings into housings make sure that:

i. your hands have been washed.
ii. the work bench is clear and wiped down clean.
iii. no one creates dust or grinds nearby during assembly.
iv. fresh, clean grease is used to pack the housing.
v. the components are clean and all old grease has been thoroughly removed.

**BREATHERS**

When protecting bearings from dust you want to always consider another important area. A breather is used to let hot air out of a confined space and then to let the air back in when it cools down. Enclosed bearings get hot when operating and cool down to ambient temperature when not in use. The air drawn back into the space needs to be clean of dust and moisture. A breather on a bearing housing or bearing housing enclosure allows ingress of moisture and dust into the bearings causing premature life failure.

Often a breather is insufficient and should be replaced with a low micron air filter that removes dust particles two micron and greater in size. Protect the breather or filter from water spray and damp conditions (ban hosing down if possible) with a shroud or by using an extension tube going into a clean, safe environment. Make sure the breather tube cannot be crushed closed by accident.

*Mike Sondalini - Equipment Longevity Engineer*

## From the mechanical workshop
## Flange bolting-up practices

**What readers will learn in this article.**

- Bolts and studs behave like springs when loads are applied.
- Gaskets behave like springs when loads are applied.
- Introduced to the use of force diagrams to explain and analyse bolt and gasket behaviour.
- Bolt torque-up issues and considerations.
- The effects of thread surface finish on friction.
- Proper bolting practices, sequence and methods.

## A BOLT IS NOT A BOLT.

A bolt is not a bolt - it is a spring! When tightening a bolt you are tensioning or slackening a spring. The sketches In Figure No. 1 show how a spring can be considered to replace the bolt pulling the flanges together.

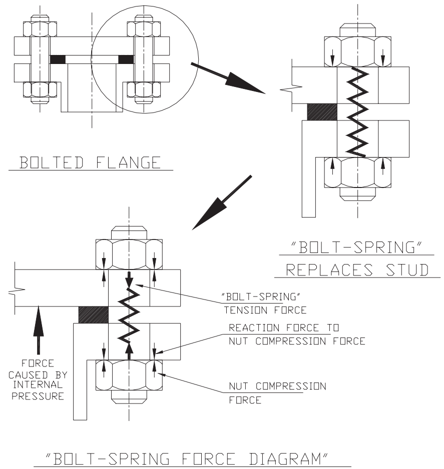


Figure No. 1. The Forces Acting on a 'Bolt-Spring'

In this article a bolt is referred to as a 'bolt-spring'. The 'bolt-spring' force must pull the flanges together more than the forces acting to push them apart. If the 'bolt-spring' is too loose, the pressure stretches the bolt and the flange opens and leaks. To prevent the flanges separating, the bolts are preloaded (stretched). Bolt torque figures are calculated to produce a bolt stretched to at least 65% of its yield strength. Yield strength is the stress at which the bolt shank starts to stretch (Take it beyond this & it will snap).

## A GASKET IS NOT A GASKET

When a gasket is sandwiched between flanges it behaves both as a seal and as a spring.. Figure No. 2 shows the gasket behaving as a spring-like material exerting its own reactive force. In this article it will be referred to as a 'gasket-spring'.

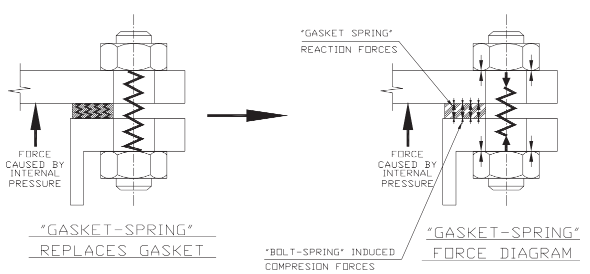


Figure No. 2. The Forces Acting on a 'Gasket-Spring'

A 'gasket-spring' will creep (squash) with time or temperature. Gasket creep is the gradual loss of the gasket's 'springiness'. The spring tension in the gasket slackens off. Gasket creep may require that flanges be re-tensioned periodically. It is often necessary to check both the bolt AND the gasket manufacturer's torque tables to select the highest allowable torque to be used.

When rubber, cork or similar soft gaskets are used the bolts can no longer be stretched to clamp the gasket in place. If the bolts are tightened the soft gasket squeezes out. When using soft gaskets only the 'spring' properties of the gasket material do the sealing. Soft gaskets must only be used for low-pressure applications. Usually an adhesive is put on the faces of the gasket to mechanically bond them to the flange faces and reduce the chance of leakage.

To prevent a flange leak there are a few things to check. The following table will provide some guidance.

| WHAT IS REQUIRED | WHAT YOU CAN DO |
|---|---|
| The bolt-spring shaft ought to be stretched to 75% - 80% of the material yield and in excess of the maximum bolt load. | Ask the bolt manufacturer for the maximum bolt torque and the number of turns from snug to achieve this or use load-indicating washers. As a last resort use a top quality tension wrench to the bolt manufacturer's torque specification. |
| Bolts of sufficient tensile strength to take the process and bolting forces. | Check the bolt head forging marks against the bolt head manufacturer's standards to insure the bolts and nuts meet the load requirements for the service. |
| Bolt tension must allow for cycling of loads, shock loads, shear loads and vibration. | Swap the bolt for one of higher tensile strength and pull it up tighter. Make sure all the bolts are to the same rating and diameter. |
| When pulling up bolts try to apply the torque evenly and continuously. | Lubricate the bolt threads lightly and follow the recommended bolting-up sequence. |
| Clean, flat flange faces | Check both flanges are clean and flat. Put a steel straight edge across each face and make sure they are flat. Machine flange faces that are not flat and leave enough thickness to still comply with pressure code requirements. |
| Use washers under the bolt head and nut. | The washer acts to distribute the load evenly and remove the effect of high spots under the head or nut causing uneven bearing. |
| The gasket must be suitable to retain the pipe contents and have negligible gasket creep. | Chose the thinnest gasket possible with high seating pressure requirements. Use new gaskets as old gaskets have lost their 'spring'. |
| Cut a neat, close tolerance gasket to completely cover the flange pressure face. | A gasket must completely cover the pressure faces to insure the flange loading evenly squeezes the gasket. |

## TIGHTENING THE BOLT AND NUT.

Tightening bolts by 'feel' is the most inaccurate method to use. Because everyone has a different 'feel' the likelihood of error is 35%. Using a torque wrench has a 25% error. Number of turns from snug a 15% error. Load indicating washers a 10% error. Measuring change in bolt length has 5% error. Measuring bolt stress is the most accurate method with a 1% error.

Figure No. 3 gives you an idea of how to gauge torque. Torque is the measure of twist produced by a force applied at a perpendicular distance from the point of twist. The sketch shows an 80-kg man standing on a one-meter long horizontal bolt spanner. This man is applying about an 800 Newton meter (Nm) torque (80 kg x 10 m/sec$^2$ = 800 Nm). But this is at sea level under full gravity, in outer space, where the man would have no weight, he could not apply a torque by this method. If the spanner were 500 mm long (half the previous length) the torque would be 400 Nm and if it were 300 mm long, the torque would be about 250 Nm.

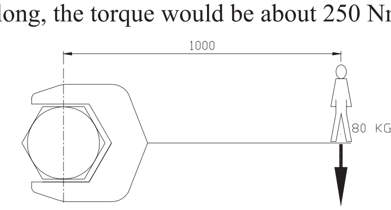


Figure No. 3. Torque on a Nut

The assembly torque that is recommended for high tensile 20-mm bolts to give 75% yield stress is about 550 Nm. A man tightening a 20-mm diameter flange bolt with a 300-mm, or even a 450-mm, long spanner would probably not generate enough force to tension the bolts. On bolts of 20 mm diameter and larger, depending on the pressure in the pipe and the type of gasket, it may be necessary to use an extension arm on the spanner or a hydraulic nut tensioner to get the needed torque.

**BOLT THREAD SURFACE FINISH**

The surface finish of the bolt and nut threads also affects the amount of torque needed to preload (stretch) the bolt. A dry galvanised bolt thread produces more friction between bolt and nut than one that is nicely machined and oiled. For the same applied torque, tightening-up dry galvanised threads would give less stretch in the bolt than tightening-up a machined and oiled thread. Tables are available that give factors by which to increase or decrease the manufacturer's recommended bolting-up torque. They vary from 2.1 for a dry galvanised thread to 0.7 for a nicely machined and oiled thread.

**BOLTING UP SEQUENCE**

The drawing in Figure No. 4 of blank flanges with flange bolt-holes shows the sequence to adopt when doing up flanges. Lightly lubricate the bolt threads after de-burring them. Insert the bolts into the flange holes and start by pulling-up all bolts finger tight. Then in the order shown, pull-up the bolts to half torque, again in the order shown, pull-up the bolts to the final torque, finally go back over all the bolts, in the order shown, and re-torque them again to the final torque to confirm all are correct. This method will sandwich in place and load up the 'gasket-spring' evenly.

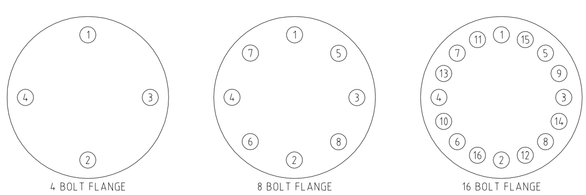


Figure No. 4. Flange Bolt Tightening Sequence

*Mike Sondalini – Maintenance Engineer*

# The Cost of Maintenance Destroys Your Capital Investment Returns

**ABSTRACT**

The cost of maintenance destroys your capital investment returns. When equipment is first selected the buyer has the choice to buy for quality and long trouble-free operating life or to buy based on least cost. The least cost choice will result in high maintenance and operating expense for the life of the equipment. When net present value cost of maintenance for cheap equipment is calculated in today's dollars investors will discover that a large part of their capital will never earn them income but will be spent on maintenance and repair. Keywords: replacement asset value, internal rate of return, opportunity cost

**Overview**

The cost of maintenance can send your business broke. If your annual maintenance cost is higher than 5% of your asset value you are in trouble.

The total maintenance cost depends on the quality of the equipment you use and how much maintenance it requires. The smart business owner buys equipment that needs little maintenance and insures that the business' design, maintenance, operating and procurement policies and practices all work toward having long-running, long-lived, never-failing plant.

**Where the Losses Arise**

It is clear to any long-serving maintenance manager that the only policy that should be adopted in a business is to buy equipment that does not fail. The cost of maintaining equipment is wasted money. Unfortunately we are forced to live within the limits of our current technologies, and for the moment, that means we only have the option of buying equipment with parts and designs that require maintenance. That being the case, it is smart business to look at getting equipment with a design that prevents failure and that requires little and simple maintenance.

In the chemical manufacturing industry the world best practice maintenance costs are 1.8% to 2.0% of the replacement value of the plant (the original asset value incremented annually for inflation). In the worst operations, maintenance costs more than 5% of the asset replacement value per year. 5% represents $50,000 per year for every $1,000,000 of asset replacement value. These organisations are unnecessarily wasting $30,000 a year for every $1,000,000 of asset value.

**The Effect of Compounding the Maintenance Cost**

Taken as an annual $30,000 sum and compounded over a twenty-year life at the business' average weighted cost of capital (12% for the sake of the calculation) the total opportunity cost involved is $2,162,000. This is money not earned over 20 years because it was spent on unnecessary repairs. If the $30,000 annual cost difference between 2% and 5% over 20 years were brought back to its present worth today (at the 12% rate) it would equal $224,000. This is $224,000 out of every $1,000,000 of asset replacement value not earning a 12% return because of poor equipment, poor design, poor maintenance and poor operating practices.

It is clearly a huge penalty for a business to pay because of inadequate design, purchasing, operating and maintenance policies and practices. The figures are even more astounding when put into tabular form on Table No. 1.

For each 1% of replacement asset value spent annually on maintenance over a 20-year period, $75,000 of every $1,000,000 of original capital will not return any dividend on the investment.

**The Best Practice to Adopt**

You may have come across these words of advice before –

"It is unwise to pay too much, but it is worse to pay too little. When you pay too much, you lose a little money. When you pay too little, you sometimes lose everything, because the thing you brought was incapable of doing the thing you brought it to do. The common law of business balance prohibits paying too little and getting a lot – it cannot be done! So if you deal with the lowest bidder, it is wise to add something for the risk you run. And if you do that, you will have enough to pay for something better." *John Ruskin. 1819 –1900, English author, architect and economist.*

"There is hardly anything in this world that some man cannot make a little worse and sell a little cheaper, and the people who consider price only are this man's lawful prey." *John Ruskin.*

"You need to be rich to buy cheap products. Why? Because you eventually have to buy twice to have the job done properly." *Anon.*

The best advice to every businessman is to only buy equipment that costs little or nothing to maintain. In fact they should be demanding that original equipment manufacturers develop new technologies for their equipment to get maintenance cost down to nothing.

With less maintenance, machinery is available to operate for longer. This translates into less spare parts, a smaller store, fewer operators, maintainers and fewer managers. The benefits gained from having reliable, long-lived plant extend well beyond just having lower maintenance costs.

If you are an investor then you may be better rewarded by putting your money into assets that require very little maintenance or into intellectual businesses that have few current assets.

If your business involves using equipment then it is critical that you buy top quality equipment requiring little maintenance. Further more, you must employ able people and train them to become the best, most competent plant operators and maintainers you can possibly afford so that they can keep plant running well and you are not wasting as much of your business' capital moneys on maintenance.

Mike Sondalini
Editor
Feed Forward Publications
Web site – www.feedforward.com.au

| Annual Maintenance Cost as % of Asset Replacement Value | Current Replacement Value of Asset in $ | Annual Maintenance as Cost of Replacement Asset Value in $ without Inflation Effect | Length of Asset Life in Years | Weighted Average Cost of Capital % | Accumulated Value of 20 Years Maintenance Opportunity Cost at Average Weighted Cost of Capital Rate | Present Value of 20 Years Maintenance Opportunity Cost at Weighted Average Cost of Capital Rate without Inflation Effect |
|---|---|---|---|---|---|---|
| 1 | 1000000 | 10000 | 20 | 12 | 720524 | 74694 |
| 2 | 1000000 | 20000 | 20 | 12 | 1441049 | 149389 |
| 3 | 1000000 | 30000 | 20 | 12 | 2161573 | 224083 |
| 4 | 1000000 | 40000 | 20 | 12 | 2882098 | 298778 |
| 5 | 1000000 | 50000 | 20 | 12 | 3602622 | 373472 |
| 6 | 1000000 | 60000 | 20 | 12 | 4323147 | 448167 |

Table No. 1. The Net Present Value of the Cost of Maintenance