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Tribology of Hydrodynamic Systems

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"HYDRODYNAMIC" SYSTEMS – it is the science which deals with the motion of an ideal & practical liquid. Thus, it uses the mechanics of moving fluids under the flow theory of fluids e.g. the conversion of flow energy into a mechanical work (centrifugal pumps, torque converter, hydraulic turbine, fluid coupling, etc.). Water and hydraulic oil (mineral oil) both are used in hydrodynamic systems.

This system is applicable in the fluid flow conditions in the transmission of motion. Here the flow equations are applicable e.g.:

Flow (Q) = Area (A) x Velocity (V)...Equation No. (1)

and **Bernoulli's principle.** The water is considered to be incompressible for most of the practical problems which may have all or any of the static, kinetic & pressure energies at a time. Thus, total energy of liquid is the sum total of all these three energies. This is known as Bernoulli's theorem & is a fundamental "**Law of Conservation of energy**" as applicable to a **flowing liquid.** Mathematically it is shown as:

Pressure head + Velocity head + Datum head = Constant or **P + ρV2/2 + ρgh = C**... Equation No. (2)

This sum is a *constant* along a streamline (Fig.-1).

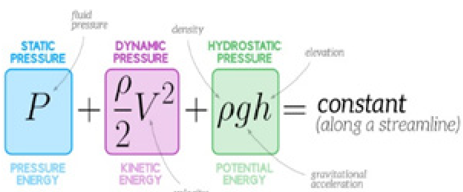

Fig.–1: Bernoulli's equation

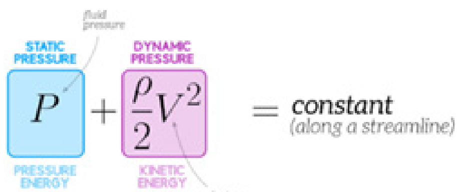

Fig.–1A: Simplified Bernoulli's equation

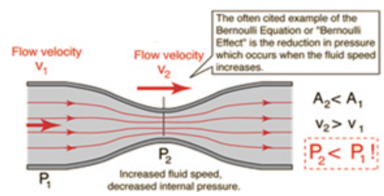

Fig.–1B: Application of Bernoulli's equation at the restriction of flow in pipe

If we assume that there is no significant change in the height of the fluid (horizontal flow), then "**ρgh**" term cancel as h=0 and we get the simplified Bernoulli's equation as shown (Fig.-1A) as **P + ρV2/2 = C**, assuming the potential energy to be negligible=0. Bernoulli's principle follows that if the speed '**V**' of a fluid is larger in a given region of streamline flow, the pressure '**P**' must be smaller in that region along the streamline (Fig.-1B).

While washing a car using a plastic pipe we press the tip of pipe, water jet is visible & car can be easily washed (Fig-2). In this case the tip area is reduced so according to Bernoulli's effect, the pressure would be less (contrary

Fig.- 2: Narrowing of pipe for car wash an example of Bernoulli's principle

to common belief). As the flow of water is constant & the area of the tip is less so the velocity of the water will be more as per flow equation No. (1). This is the kinetic energy of the water. According to simplified Bernoulli's equation (2): **P + ρV2/2 = C**, as the velocity of water '**V**' is more, the pressure of water '**P**' at that point (tip point) will be less than before as it has gained the kinetic energy. **Thus, the Bernoulli's principle is used in any flow of fluid condition like in pipe nozzle, centrifugal pump, torque converter, water turbine, Archimedes screw etc.**

Hydrodynamic Systems with WATER for House Hold & Industrial Applications

Centrifugal Pump

Now centrifugal pumps are the world's most commonly used pumps to move fluids. These pumps are often used for pumping any low-viscosity liquid in domestic, industrial, agricultural etc, applications. They form a very big part of urban living. The commonly known Tulu pumps are small pumps used for lifting the water to reduce the load of water carrying from lower to upper stairs in the house. In centrifugal pump, the liquid goes through the inlet i.e. impeller having series of curved vanes– the key component – the heart of a centrifugal pump. Fluid enters the impeller at its axis (the 'eye') and and is pushed outwards by means of a centrifugal force towards the periphery of the impeller & finally goes away along the circumference of the vanes (Fig.-3).

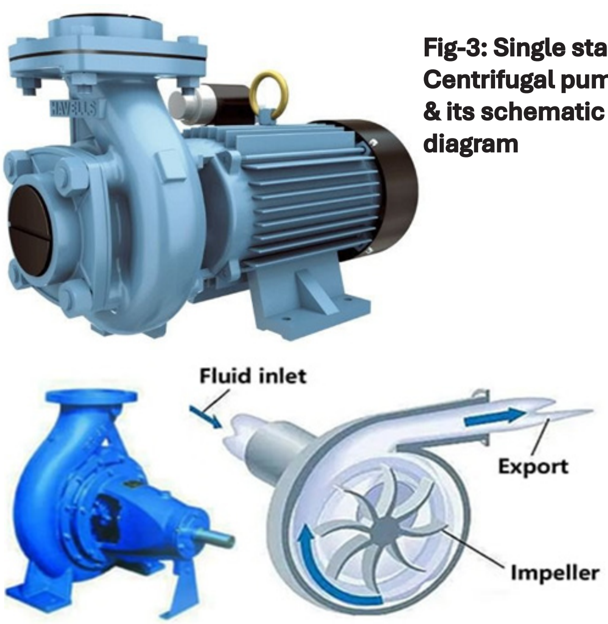

Fig-3: Single stage Centrifugal pump & its schematic diagram

The rotational motion of the impeller accelerates the fluid out through the impeller vanes into the pump casing which is specially designed to constrict the fluid from the pump inlet, direct it into the impeller, then slow it and control the fluid before discharge at high pressure normally called as "head". This device is most often used to transfer fluid between two different locations in a broad range of industrial applications, including municipal (water and sewage facilities), power generation, mining, agricultural, and the petroleum and chemical sectors, among several others.

Hydraulic Turbines

In hydroelectric power plant the erosions on the runners of turbine (Fig-4) have a significant impact in hydroelectric energy generation. This erosion is because of the corrosion by hard & suspended particles, which is due to the high concentration of sediment that originates from run-off-river that strike to the turbine runners, causing wear and tear of the mechanical components. In case of power plants under Himalayan Rivers, the turbines need to undergo repair and maintenance in a regular basis, due to a substantial erosion loss of material from the turbine runners.

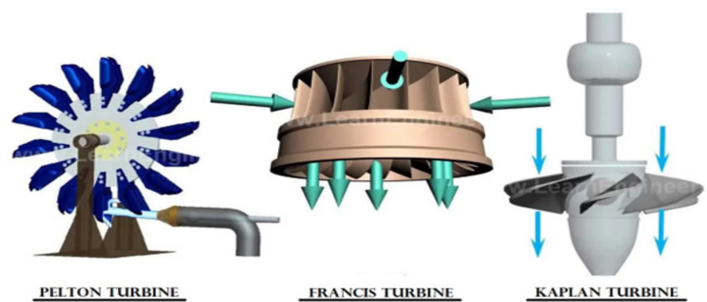

Fig-4: Various turbine runners

Hydrodynamic systems with MINERAL OIL (special industrial application)

The automatic transmission forms a system in which gearshifts are automatically actuated through **the torque converter.** Torque converter takes the place of the clutch found on standard shift vehicles having a large doughnut shaped device that is mounted between the engine and the transmission. It uses oil (transmission fluid) to transmit power through basically of three elements: the turbine, the stator, and the impeller.

Finally in transmission, the direction of transmission fluid goes on various paths by solenoid valves (electronically controlled control valves) in accordance with sensor information on the vehicle speed, throttle opening, and other aspects of vehicle operation. The power finally moves through different set of planetary gears for different gear ranges as per the vehicle speed. They are used in the automatic transmission in payloaders, heavy-duty trucks/trailers (Figs-5, 6, 7).

Fig-5: Payloders

Fig-6: Heavy Duty Trucks

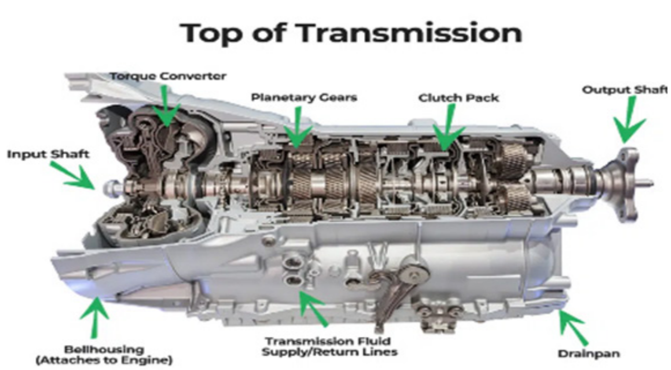

Fig-7: Automatic Transmission with fluid torque converter

Tribology solutions for hydraulic turbines due to water erosion

Coating on the turbine runners' hard surface with an erosion-resistant hard surface coating is one method for decreasing the effect of erosion (Fig-8). In the Nepalese hydropower sector, ceramic pastes, ceramic paints, and strong welding alloys are frequently employed. In the High Velocity Oxygen Fuel (HVOF) process, hydropower firms have lately employed tungsten carbide-based ceramics (86WC-10Co-4Cr). Spray parameters and particle properties influence the performance of such coatings. The erosion resistance of a similar coating measured on high velocity jet erosion test equipment demonstrates that the same powder sprayed by different coating manufacturers exhibits varying erosion resistance. The coated turbine at the Cahua power plant increased energy output by 13.1 GWh during the same time period, which is nearly a 50% increase over the uncoated turbine's output. (as reported by *Shekhar Aryal et al*).

Fig-8: Erosion of Peltton runners

Tribology solutions for gears in loss of lubrication (LOL) conditions

Loss of lubrication (LOL) in any oil wetted systems is a common phenomenon denoted by starvation of lubrication which causes metal-to-metal contacts (highly undesirable) e.g. in torque converter, automatic transmission, heavy reduction units/ gearboxes, hydraulic systems using the mineral/ synthetic oil, aerospace operations - all refers to a malfunction of the lubrication system. This can be due to oil losses caused by leakage, off-design conditions such as windmilling or overheating of the system etc. Under LOL, the oil supply is interrupted and machine elements such as gears and bearings are no longer lubricated as designed, thus exposed to overheating which leads to increased friction and wear in tribosystems. It causes, surface failures of gears and bearings, such as scuffing etc. Scuffing of gears occurs suddenly and leads to instantaneous welding of the mating gear flanks with failures in corresponding flank areas. This causes damage to the gear profile. Continued operation under LOL will result in a drastic increase of component temperatures and thermal overheating & loss of power transfer in gearboxes. Synthetic oil gives better results in such cases.

Fig-11 (A): Impeller Coating

Fig-9 (B): Effect–Impeller Coated, after 6 months in sewerage operation

Coatings: Abrasion-resistant coatings to extend the service life of pump impellers

Solid impingement, changing viscosity of the pumped liquid, abrasive and impacting loads—this is the reality of a typical pump impeller. It's no wonder that expectations regarding the operating lifespan are limited. Just like in real life—with increasing age, the performance, or to put it technically correctly, the pump efficiency, decreases rapidly. Coatings are applied when high wear resistance, reduced friction, or longevity are needed. (Fig-9, 9A & 9B). DLC (**Diamond-like carbon**) coatings show great potential for friction and wear reduction in both lubricated and LOL conditions due to their high hardness, heat, and wear resistance. DLC coatings can be deposited by a wide variety of physical and chemical vapor deposition techniques (PVD and CVD, respectively). These coatings can exhibit low friction, very high hardness, excellent wear resistance, and chemical inertness for corrosion resistance (Martins et al. 2008). Triboactive coatings result in increasing or decreasing COF depending on the reduction of temperature due to friction.

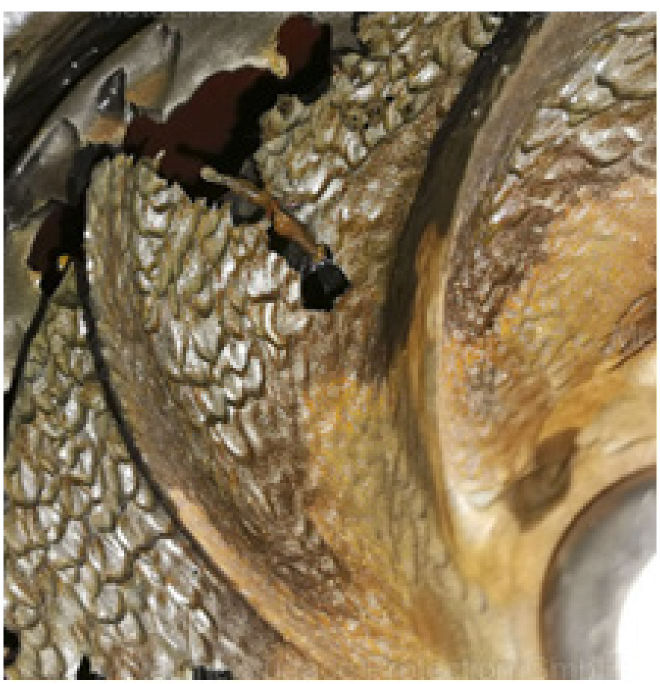

Fig-11: Effect–Impeller Without Coating, after 6 months in sewerage operation

The secret is in the lining—fluoropolymer materials

Corrosive materials are some of the trickiest substances to handle, demanding not just great care, but also a careful selection of the type of pump. Chemical process pumps lined with fluoroplastic materials such as PFA (Perfluoro alkoxy tetra fluoro ethylene), ETFE (Ethylene tetra fluoro ethylene) and PVDF have excellent corrosion resistance capabilities, especially PFA.

Surface finishing

While superfinishing of gear flanks is an established method of reducing gear friction in lubricated conditions, the effect is less distinct in LOL. ◆

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