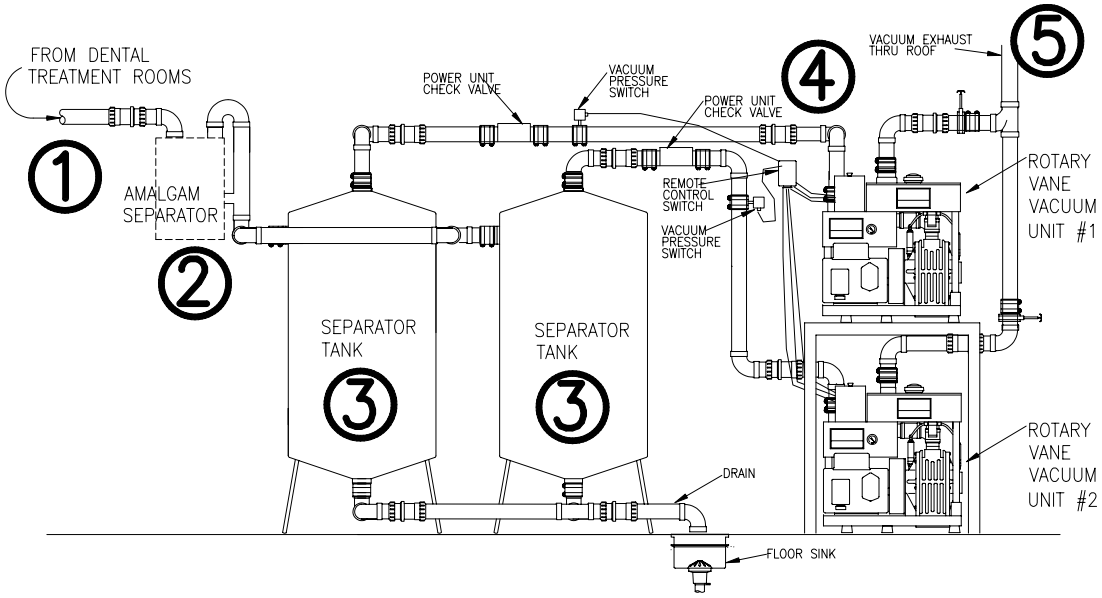
DENTAL VACUUM SYSTEMS

Introduction

The following article reviews dental vacuum system nomenclature, components, and function, and briefly discusses the concepts of vacuum and airflow. Dental vacuum systems operate at a relatively low vacuum level (typically 6-8 inches mercury) and a relatively high airflow (typically 7 standard cubic feet per minute per chairside high volume inlet). For this reason these systems sometimes are referred to by two different names. They are referred to both as Dental Low Vacuum (DLV) systems as well as High Velocity or High Volume Evacuation (HVE).

Typical dental vacuum schematic for a moderately large facility



The schematic above illustrates a dental vacuum system utilizing two separator tanks and two rotary vane vacuum pumps. Dental vacuum systems are categorized as Level 3 systems under the National Fire Protection Association Code 99 (NFPA 99).

1. A **central vacuum pipe** enters the mechanical room from the dental treatment rooms.

2. Fluids and debris travel through an **amalgam separator**. The requirement to include an amalgam separator in the system varies by locality. Amalgam and debris are retained in the amalgam separator, while fluids pass on to the separator tank or tanks.

3. **Separator tank** quantity and size are dependent upon the facility size. Twin separator tanks are illustrated in the schematic above. Fluid from the incoming vacuum line is held in the

separator tanks until the end of the day. When the vacuum system is turned off at the end of the day, a valve at the bottom of the separator tank opens and the fluids exit through a drain.

4. Dry piping (all fluid remains in the separator tank) connects the separator tank(s) with the **vacuum pump(s)**. Two or more pumps are used in all but the smallest Air Force facilities. The pumps are controlled such that one pump is the primary, or lead, pump on any given day and the remaining pump or pumps are secondary, or lag, pumps. The lag pump(s) only kick in when demand exceeds the lead pump's capacity. The pumps are automatically cycled such that each day a different pump serves as the lead pump. MIL-HDBK-1191 (Medical Military Facilities Design And Construction Criteria) recommends that the two (or more) pumps together are sized to meet 100% of the total system demand. The pumps are also sized such that if one pump becomes nonfunctional the remaining pump or pumps will handle at least 70% of the total system demand. This 70% of system demand is usually sufficient for normal clinic operation, as it is rare for a clinic to operate such that 100% of the system demand is utilized.

5. Exhaust from the vacuum pump(s) is vented through **exhaust piping** to the exterior of the facility.

Wet versus dry vacuum piping and pumps

Dental vacuum systems consist of two primary components--the piping run and the vacuum pump or pumps. Vacuum systems are sometimes classified as either “wet” or “dry,” but this can cause confusion as the piping run can be wet or dry and the pump can be wet or dry. It is better to speak about wet or dry piping and wet or dry vacuum pumps.

Wet piping - The term “wet piping” refers to pipe through which water and evacuated fluids are transported from the dental treatment room to a centralized vacuum pump in a mechanical room. Dental vacuum systems typically utilize wet piping.

Dry piping - No water or fluids are transported through dry piping. Water and evacuated fluids are collected in a suction canister in the dental treatment room, and then the piping run from the dental treatment room to the centralized vacuum pump is dry. Surgical vacuum systems typically utilize dry piping runs.

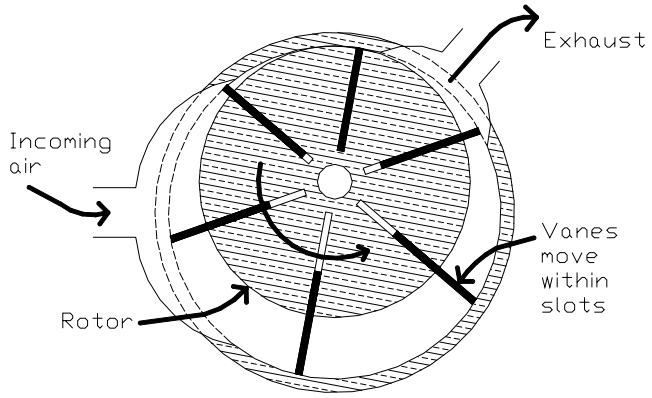
Wet vacuum pump - This type pump is termed “wet” as it is typically connected directly to wet piping from the dental treatment rooms. Water and evacuated fluids from the incoming pipe are mixed with fresh water which then passes directly through the pump and out to the drain. A water-ring pump (also called liquid-ring pump or liquid-injection pump) is a wet vacuum pump.

Dry vacuum pump - With a dry pump, a liquids separator is placed between the wet piping and the pump. In a typical setup, wet piping from the dental treatment area enters the mechanical room, and then connects to a large separator tank. Water and evacuated fluids remain in the separator tank, then dry piping connects the separator tank to the vacuum pump.

Dry vacuum pumps

Rotary vane pumps

While turbine pumps are probably the most common type of pump in existing USAF dental facilities, rotary vane pumps have been placed in many recent USAF projects and are functioning very well. These pumps are quite reliable and have some of the longest warranties in the industry. In very large facilities, systems are often configured with more than two pumps and the system is controlled by a microprocessor. When demand is low, unneeded pumps are shut down. When demand increases, the microprocessor turns on additional pumps as needed. This conserves power and the multiple pump design provides excellent backup capability. At typical dental airflow and vacuum levels utilized in the United States, a vacuum system incorporating rotary van pumps requires less electrical power than a system incorporating turbine or water ring pumps.



Rotary vane pump schematic

Rotary vane pump example

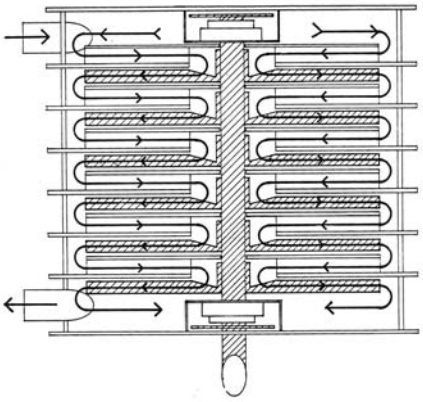
Rotary vane pump operating principals

A central separator tank is located in the mechanical room between the vacuum pipe (coming from the treatment rooms) and the rotary vane pump. All fluids and debris from the treatment rooms are removed from the vacuum line in the separator tank so that a dry pipe connects the separator tank to the rotary vane vacuum pump. Inside the pump, a slotted rotor is positioned eccentrically within the pump chamber. Vanes (rotor blades) fit within the slots. As the motor causes the rotor to spin, centrifugal force and/or pushrods force the vanes to move down the slots away from the rotor center to contact the chamber walls. The eccentric location of the rotor within the chamber results in the formation of spaces of differing volume between the vanes, the chamber wall, and the rotor. The inlet and outlet ports are located such that the inlet port is positioned in an area where these spaces are increasing in volume (thus creating the vacuum effect) and the outlet port is located in an area where these spaces are decreasing in volume (thus compressing the air and forcing it out the exhaust).

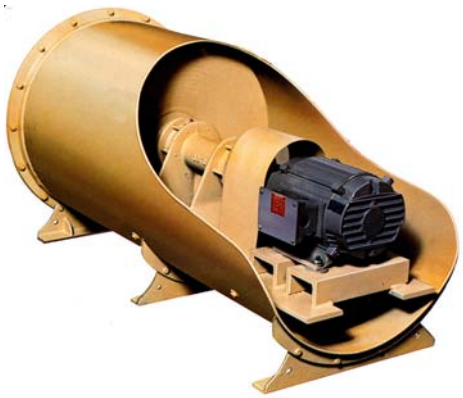
Turbine pumps (also called centrifugal exhauster)

The term "turbine" refers to a machine that generates mechanical power when a stream of gas or liquid passes through it. For that reason, a vacuum pump of this design is not truly a turbine as it is not air movement that drives the rotor blades, it is the reverse…rotor blades (powered by an electric motor) cause air movement. The term used for this type machine in industry is "centrifugal exhauster." However, to stay with dental conventional terminology, the term "turbine" will be used in this article.

While rotary vane pumps have been placed in many newer facilities, turbine pumps are probably the most common type of vacuum pump found in existing USAF dental facilities. These pumps are capable of producing high airflow and adequate vacuum pressure (though the vacuum pressures are generally not as high as that attainable with rotary vane pumps).



Turbine pump schematic



Turbine pump example

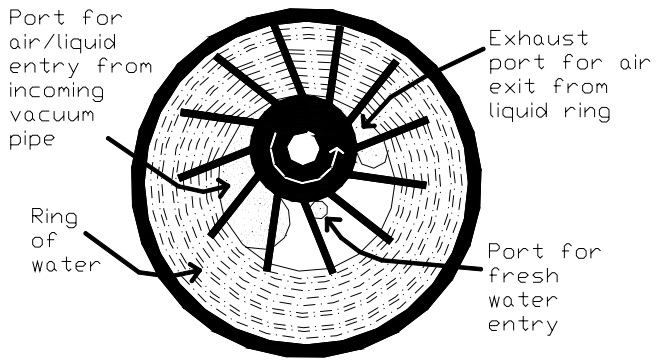
Turbine (centrifugal exhauster) operating principals

As with a rotary vane system, a central separator tank is located in the mechanical room between the vacuum pipe (coming from the treatment rooms) and the turbine pump. All fluids and debris from the treatment rooms are removed from the vacuum line in the separator tank so that a dry pipe connects the separator tank to the turbine vacuum pump. The turbine pump contains a series of blades, or impellers, mounted on a common shaft. The impellers rotate in a series of chambers and each chamber/impeller combination makes up one stage of the pump. The dimensions and design of the impellers as well as the number of stages influence the maximum attainable vacuum level (increasing the number of stages increases the maximum attainable vacuum level). Air enters the first chamber and is accelerated away from the shaft by the first impeller. At the outer edge of the chamber, the air is redirected 180 degrees into an empty chamber back toward the shaft. Pressure increases in this chamber and the air then enters the next stage's impeller chamber and the process is repeated with the pressure increasing at each successive stage resulting in a vacuum at the inlet.

Wet vacuum pumps

Water-ring pumps (also called liquid-ring or liquid-injection pump)

Water-ring pumps are commonly used in smaller dental practices, but are infrequently used for larger military HVE systems due to high water consumption and increased power requirements compared to other available pump designs. Water usage can be reduced through use of a water recycler, which recycles much of the liquid back through the pump, adding fresh water to it. Water recyclers can reduce water usage by approximately 80%. A typical one horsepower water-ring pump for a small facility with a recycler uses approximately 15 gallons of water per hour. Water-ring pumps can produce fairly high vacuum levels, up to approximately 25” Hg.



Water-ring pump schematic

Water-ring pump example

Water-ring pump operating principals

A dental water ring pump is typically connected directly to the incoming vacuum pipe from the dental treatment rooms…there is no central separating tank between the pipe coming from the treatment rooms and the pump. Water, other fluids, and debris enter the pump and first pass through a collection trap. This trap removes debris too large to pass through the pump. The remaining water, other fluids, and smaller debris particles then pass into the pump's chamber. While some water/liquid enters the chamber from the vacuum piping, most of the water that forms the liquid ring in the chamber is fresh or recycled water which enters the chamber through a separate port. An impeller is positioned in an eccentric position within the chamber. When the impeller rotates, the water/liquid mixture is thrown by centrifugal force against the chamber periphery and this forms the liquid ring. The eccentric location of the impeller within the chamber results in the formation of spaces of differing volume between the impeller blades, the ring of liquid, and the impeller shaft. The inlet and outlet ports are positioned interior to the liquid ring such that the inlet port is located in an area where the space between the liquid ring and the impeller shaft is increasing resulting in an expanding volume (thus creating the vacuum effect) and the outlet port is located in an area where the space between the liquid ring and the impeller shaft is decreasing resulting in a contracting volume (thus compressing the air and

forcing it out the exhaust). The constant entry and exit of water/fluids through the pump can result in significant water consumption. As mentioned above, water recyclers are available which return a portion of the exhausted fluids back into the chamber, thus reducing total water consumption.

Vacuum and airflow

Performance of a dental vacuum system is based on two properties: vacuum and airflow. In the United States, vacuum is generally referenced as inches of mercury (" Hg) and airflow as cubic feet per minute (CFM). Vacuum provides the energy, or "lift," for transporting material through the system and airflow relates to the volume of air transported and its ability to capture aerosols. (Note: airflow is measured at actual pressure and temperature conditions [actual cubic feet per minute, ACFM], but for consistency is usually converted to standard conditions [14.69 PSIA, 60 degrees F] and reported as standard cubic feet per minute [SCFM]).

For any given size orifice (for example the high volume evacuation [HVE] tip on a dental unit), airflow through the tip is related to the vacuum level within the dental unit hose, which, in turn, is related to the vacuum level generated at the vacuum pump. For a given system, the greater the vacuum created at the pump, the greater the airflow through the HVE tip. Consideration must be given to vacuum losses between the pump and the HVE tip which arise from flow resistance of the piping runs, flow resistance within the dental unit itself, and potential vacuum decreases due to flow increase from other HVE units operating simultaneously if the capacity of the pump is exceeded. An airflow value of 7 SCFM at the HVE tip is generally considered acceptable for clinical dentistry. For most dental vacuum systems, a vacuum level of 6-8" Hg (as measured at the pump) is usually sufficient to produce this 7 SCFM airflow at the HVE tip assuming a properly designed piping system and properly maintained treatment room equipment. For a typical facility with below grade piping (below the floor), pump selection is based on the size and quantity of pumps required to maintain this 6-8" Hg vacuum given the total airflow requirement derived from the number and type (HVE versus saliva ejectors, etc) of expected simultaneous users.

Note that the above paragraph references a typical facility *with below grade piping*. Most military facilities are constructed with vacuum piping below grade, but occasionally a facility will have the need to place the vacuum piping overhead (above the ceiling). Overhead piping is discouraged. With overhead piping, you are asking the vacuum system to lift fluids up a significant vertical run…from below the floor to above the ceiling. Proper pipe configuration is critical with overhead piping. Also, a system vacuum strength greater than the typical 6-8" Hg is required. A vacuum pressure of 9" Hg is required to raise a bolus of water up a 10-foot rise. This 9" Hg figure gives no safety factor, so the actual system vacuum would have to be capable of a vacuum level greater than this. Some vacuum pumps are not capable of generating vacuum levels in this range. Incomplete transport of fluids up the vertical rise could yield buildup of fluids in the dental unit vacuum lines and a nonfunctional system.

A final note regarding the relationship between vacuum and airflow. The above discussion referenced the fact that the airflow through a given size orifice/pipe would increase if the

vacuum level at the pump were increased. This direct relationship assumes a constant pipe/orifice size. However, in a functioning system, if an orifice of one size (such as an HVE tip) is replaced with an orifice of another size (such as a surgical tip), vacuum and pressure are inversely related. Think of this in terms of what happens when you occlude the end of a dental high volume evacuator (HVE) tip. If you totally occlude the opening with your hand, you can feel the greatest vacuum pressure, but the airflow is zero. When you remove your hand from the opening, the vacuum pressure decreases, but the airflow through the hose increases. Similarly, if you replace a standard dental HVE tip with a smaller diameter surgical tip, the vacuum pressure in the tip will increase as compared to the HVE tip, but the airflow will decrease. The most effective dental vacuum performance occurs when there is a proper balance between vacuum pressure and airflow. You want enough vacuum “energy” or “lift” to remove liquid and solid matter and you want enough airflow to capture aerosols.