Application of Hydrocyclone for Wastewater Treatment in Wine Industry

Alexander Bagration-Davitashvili, Zaal Tsinadze, Ketevan Gordeziani, Maka Mzhavanadze
Georgian Technical University, M. Kostava 77, Tbilisi 0159, Georgia.
adavitashvili@gtu.ge
DOI: https://doi.org/10.52340/building.2025.72.02.23

bstract Global water scarcity is increasing in many regions causing a deficiency in agricultural, human and industrial needs. Industrial activities produce wastewater and solid waste streams needed management. These waste streams have a negative environmental impact. Therefore, wastewater treatment will be important to solve the problem.
The varying amounts of generated winery wastewater, together with their composition during the winemaking process, pose a challenge for wineries when selecting suitable treatment methods. A general trend in winery wastewater treatment, where the shortcomings of many techniques are related to the variations in the organic content and volume of the wastewater.
A single operation is generally not sufficient to improve the quality of wastewater treatment for discharge into the environment. However, hydrocyclone treatment is a promising technology. Hydrocyclone treatment technology has become more popular and accepted in recent years for the treatment of many types of wastewaters, while conventionally activated sludge processes cannot. handle the composition of wastewater or fluctuations in the wastewater flow. According to our research, hydrocyclone treatment makes it easier to treat winery wastewater at lower costs.
Key words: Hydrocyclone, Winery Wastewater, Wastewater Treatment

Introduction

A hydrocyclone is a device used in water purification processes for the efficient separation and classification of particles in suspensions [1,2]. It is a cylindrical device whose operating principle is based on centrifugal force. This technology converts water flows containing mixed particles of varying sizes and densities into a clean product ready for further use.
A hydrocyclone allows for the highly accurate separation of solid particles from liquids, making it widely used in wastewater treatment plants. The design includes a slurry feed port through which the material is injected under pressure into the device.
A rotating flow is created within the device, where centrifugal force separates the particles by size and density. Heavy and large particles are forced to the periphery and removed through the lower outlet, while lighter and smaller particles, along with water, are carried away through the upper outlet. The hydrocyclone's operating principle is based on using water as a medium to create a centrifugal field, ensuring high separation efficiency with minimal loss of useful material. Hydrocyclones employ a unique separation method based on the principle of centrifugal classification. This process is key to the device's operation and occurs in an aqueous environment. A key feature is its ability to separate solid particles from suspension, making it effective in wastewater treatment.
During operation, wastewater is fed under pressure into the cylindrical section of the device, where a rotating flow is created. Under the influence of centrifugal force, heavier and larger particles are displaced toward the periphery and settle at the bottom of the hydrocyclone, where they are then removed. Meanwhile, lighter and smaller particles, along with water, rise to the center of the vortex and are removed through the upper outlet.
In wastewater treatment plants a hydrocyclone plays a vital role, ensuring high efficiency at minimal cost. When the slurry, a mixture of liquid and solid particles, is fed into the hydrocyclone, it enters a vortex. Under the influence of centrifugal force, heavier and larger particles are moved toward the outer wall of the apparatus and removed through the lower discharge pipe. Meanwhile, lighter particles and water are carried by the central part of the vortex toward the upper outlet.

Hydrocyclones are ideal for cleaning applications requiring a high degree of material separation. The hydrocyclone's effectiveness in cleaning stems from its ability to process large volumes of suspension while maintaining high separation accuracy and minimizing loss of valuable raw materials.

Hydrocyclone Design

The hydrocyclone design is a unique combination of simplicity and engineering sophistication, ensuring its high efficiency. Its main elements are a cylindrical upper section, a conical extension, and material inlet and outlet ports (Fig. 1).

The cylindrical section serves to introduce the slurry, which is introduced through a side port under pressure. The conical lower section collects and removes heavier particles that settle under centrifugal force.

The upper section houses the discharge port (upper), through which the clarified liquid is removed along with smaller, lighter particles. The lower discharge port is used to remove heavy particles that have settled in the conical section.

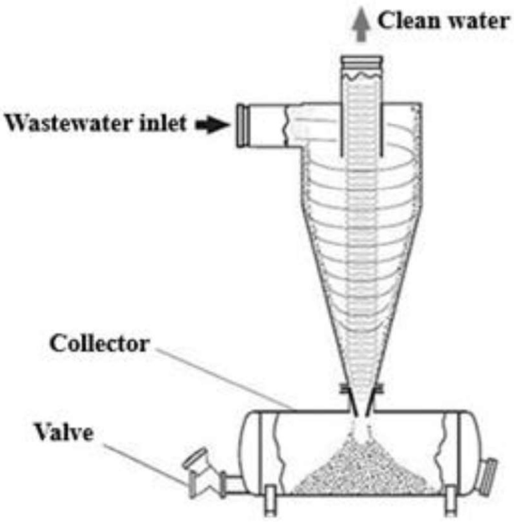

Fig. 1. Hydrocyclone design diagram

One of the most common types is the classic hydrocyclone, a cylindrical-conical shape. It is effective at separating heavy particles from lighter, smaller ones. They are widely used in wastewater treatment.

Characterisation of wine industry wastewater

Wine industry enterprises include grape juice distilleries, primary wineries, champagne distilleries, cognac distilleries, and municipal wineries.

Winery wastewater is a major waste stream generated by the many cleaning operations that occur during each phase of production. The wastewater produced contains a variety of pollutants. The volume and pollution vary significantly depending on the operating period (harvest, storage, bottling) and the winemaking technologies used (e.g. red, white and specialty wines).

Wastewater at grape juice distilleries is generated because of the following technological processes: juice cooling in coolers, separation in separators and refrigeration compressor stations, and cleaning equipment, pipelines, and floors. In addition, there is also domestic wastewater.

Processing 1 ton of grapes generates 1.08 m^3 of wastewater (including the recycling water supply system and consistent water use). Of this amount, 0.28 m^3 is produced by industrial wastewater, 0.02 m^3 by domestic wastewater, and 0.78 m^3 by relatively clean water. During the winemaking period, 0.19 m^3 of wastewater is discharged to produce 1 dl of grape juice. Primary wineries produce wine from fruit raw materials. The wastewater generated here consists of rinsing and flushing water, which contains contaminants such as stems, leaf debris, and small particles of damaged fruit.

Wine production faces many serious environmental challenges. The main potential environmental impacts of wineries are:

• Groundwater and surface water pollution, soil degradation and vegetation damage resulting from the reuse and disposal of liquid and solid waste

• Odors and air emissions resulting from the management of raw materials, wastewater, solid and semi-solid by-products of the winemaking process; noise from pumps, chillers, crushers and other winemaking equipment, as well as noise from machinery, especially during the harvest.

The main environmental problems associated with the operation of wineries fall into six categories: wastewater, water and energy consumption, solid waste, chemical use, and air emissions.

Wastewater from urban wineries and primary winemaking plants is similar in quantity and pollution levels. During grape processing, wastewater discharge, considering the recirculating water supply system, is 1.14 m^3 per 1 g of grapes; of this, 0.74 m^3 is production wastewater, 0.02 m^3 is domestic wastewater, and 0.38 m^3 is conditionally clean wastewater. During the winemaking period, the production of 1 dl of wine generates wastewater of 0.05 m^3, 0.04-0.001 m^3, and 0.009 m^3, respectively. At cognac distilleries with a water supply system with sequential use of water, the discharge is 1.47 m^3 to produce 1 dl of cognac spirit, of which 0.29 m^3 is production waste, 0.01 m^3 is household waste, and 1.17 m^3 is relatively clean waste. The coefficient of unevenness of wastewater inflow at both plants in summer and winter is equal to one.

The content of organic matter, salts, macro- and microelements in the sludge from winery treatment facilities is:
Organic matter, % - 37.7
Mineral matter, % - 53.7
Total nitrogen, % - 2.58
Total phosphorus, % -1.3
Hygroscopic wet, % - 8.6
Potassium, mg/100 g soil - 62.3
Phosphorus, mg/100 g soil - 9.9
Titanium, mg/1 kg soil - 1701
Copper, mg/1 kg soil - 459
Manganese, mg/1 kg soil - 360
Chromium, mg/1 kg of soil - 296
Boron, mg/1 kg of soil - 196
Nickel, mg/1 kg of soil - 106
Cobalt, mg/1 kg of soil -135
Molybdenum, mg/1 kg of soil - 178
Zinc, mg/1 kg of soil - 2800-3400
Lead, mg/1 kg of soil - 160-230
Strontium, mg/1 kg of soil - 160-230

Application of Hydrocyclone for Wastewater Treatment in Wine Industry

Winery wastewater is typically described as a mixture of fresh water, readily soluble and biodegradable organic material such as proteins, polypeptides and polysaccharides, dissolved salts, minerals and low concentrations of heavy metal ions and other phytotoxic and persistent compounds. Raw wastewater must undergo treatment to meet wastewater quality requirements.

In most cases, wineries use a combination of treatment phases, including pre-treatment, primary, secondary and tertiary treatment phases. A final treatment stage is also often used to disinfect the treated wastewater, which largely depends on its destination.

Three main variations of treatment are mainly used: physicochemical treatment, biological treatment, and advanced oxidative treatment.

In most cases, wineries use a combination of processing phases, which include pre-, primary, secondary, and tertiary processing phases [4,5,6].

We propose the treatment of winery wastewater using hydrocyclone.

The advantages of hydrocyclone are:

- Reduced processing time: The processing time is very low (approximately 2-3 seconds) compared to other traditional gravity systems.
- No moving parts: The separation is carried out entirely by gravity, so there are no moving parts in the system, which results in less maintenance and operating costs.
- No chemicals are required: The system is self-cleaning due to the effect of gravity; therefore, no chemicals are required during operation.
- Continuous process: Since the system does not need to be backwashed, the service life is very high.
- Modularity: Ability to operate at a wide range of flow rates, in the case of low flow rates, by changing the working elements.
- Energy consumption: They do not require energy to operate and are relatively inexpensive.
- The maintenance of hydrocyclone does not require complex equipment or qualified personnel. In terms of technical capabilities, hydrocyclones can compete with other water treatment methods, offering undeniable advantages over some of them.

For example, compared to sedimentation tanks, hydrocyclones require minimal installation space.

The results of laboratory data processing clearly show the high degree of removal of organic substances from liquids at different concentrations using a small diameter hydrocyclone. When increasing the concentration from 1 to 10 g/l, the degree of removal decreases from 98.95% to 93.50%, based on the dry residue of treated wastewater and winery wastewater.

In the case of a nozzle diameter of 7 mm, a better removal rate was obtained than in the case of a diameter of 6 mm, which demonstrates the possibility of controlling the quality of removal by this method.

With an increase in the concentration of organic substances to 10 g/l, the proportion of large particles increases. These particles settle out during water circulation in the tank, thereby affecting the analysis results, since the pump takes up the suspension from the bottom of the tank. Therefore, the removal results were calculated based on the ratio of the mass of particles in the treated wastewater to the mass of particles in the sand wastewater.

The object of the study was a laboratory analogue of wine production wastewater, which contains suspended particles of organic compounds at a concentration of 1–10 g/L, which corresponds to the size of particles present in winemaking wastewater.

The results of laboratory tests showed a high removal rate of organic matter particles from the recirculated water model samples from the liquid ring pump cycle. Hydrocyclonic treatment at low particle concentrations (1 g/l) is effective even without the use of post-treatment filters. However, to achieve consistent treatment results at all possible concentrations of organic compounds (from 5 to 40 g/l), it is necessary to treat the recirculated water using two volumetric filters. This allows for rapid treatment of the recirculated water during alternating operations of the recirculation and regeneration.

The collected samples were filtered through filter paper and dried in an oven at 110°C for 40 minutes to remove free water. The difference in the weight of the filter paper before and after filtration was used to calculate the dry residue separated in the waste stream and the weight of the particles in the hydrocyclone. The degree of purification was calculated using the following ratios:

$$X = \frac{m_{oc}}{m_{dw}} \times 100\%$$

X – Degree of suspension purification to initial concentration, %M_{oc}-Mass of the organic compound sample, gM_{dw} – Mass of dry waste resulting from the hydrocyclone discharge, g

$$X_1 = \frac{m_{\text{d}}}{m_{\text{d.d}}} \times 100\%$$

where X_1 - is the rate of purification of the solution of discharged organic substances, %;$m_{d.}$ - is the weight of dry residues of discharged organic substances, g;$m_{d.d.}$ is the weight of dry residues discharged from the hydrocyclone.

The rate of solution purification in relation to the discharge of organic substances considers the uneven mixing during the operation of the hydrocyclone cycle under laboratory conditions. Under industrial conditions, coarsely weighed substances do not have time to settle in the supply pipeline and remain stable.

Based on the research conducted, the following optimal dimensions of a D_{50} hydrocyclone are recommended for removing organic matter from recirculated water at a pressure of P = 2.0 kg/cm^2:

Height of hydrocyclone h	250 mm
Hydrocyclone diameter dc	50 mm
Height of cylindrical part h_c	50 mm
Cone angle θ°	8–10°
Capacity	4.3 m^3/h
Drainage pipe diameter d_{dpd}	17.0 mm
Inlet diameter d_{id}	13.6 mm
Solution filler diameter d_s	9.3 mm
Length of drainage pipe inside hydrocyclone l	57 mm

Laboratory and calculated values for the performance of the hydrocyclone show that this type of device can be used as a primary unit for cleaning recirculating water from liquid-ring pumps. The use of a sedimentation tank with a thin-film module requires a longer retention time of the organic matter suspension in the device, higher costs of equipment and instruments, and a greater load on the equipment.

Conclusion

It should be noted that the treatment of winery wastewater by the traditional convection method, which includes mechanical cleaning, coagulation-flocculation, sedimentation and disinfection, is not sufficient for sufficient treatment of winery wastewater.

At the same time, the impact of wineries on the environment leads to pollution of groundwater and surface waters, soil degradation and damage to vegetation cover, which occurs due to the impact of liquid and solid waste.

The treatment of winery wastewater by means of a hydrocyclone is discussed and its parameters are proposed based on the analysis of the obtained laboratory results.

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