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**Research Article / Araştırma Makalesi**

# AN EXPERIMENTAL STUDY OF MECHANICAL EFFECT IN CLEANING PROCESS

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## ABSTRACT

Cleaning is the process of using water and detergent to remove soil, rust stains or other deposits from surfaces. The cleaning performance is the most important competitive factor. The main parameters that influence the cleaning performance are chemicals, water temperature, cleaning time and mechanical impact on the surfaces. This paper is related with mechanical impact of cleaning processes. A Water Jet Test Apparatus was used to measure the force, generated by a jet of water as it strikes the surface under various experimental conditions. Measured values were between 0.09 and 0.49 N, these were a function of flow rates, angle of impact surface, distance from nozzle to impact surface and cross-sectional area of nozzle. The results showed that the higher flow rate provides a greater impact force with the same nozzle. If the cross-sectional areas of nozzles increase, the water jet impact forces decrease on similar flow rate values. For same experimental conditions, the jet impact force increases with angle of impact surfaces, reaches a maximum value on 90º. The most effective parameter on force was impact of flow rate. As a result of tests, effectiveness of impact of flow rates were 59%, effectiveness of cross-sectional areas of nozzles were 21% and effectiveness of angle of impact surfaces were 15%. The impact of distance from nozzle to surface had limited effect on the jet force.
**Keywords:** Mechanical impact, water jet, jet force, impact surface, nozzle, flow rateç.

## YIKAMA İŞLEMİNDE MEKANİK ETKİNİN DENEYSEL OLARAK İNCELENMESİ

## ÖZ

Yıkama prosesi, kullanım sonunda yüzey üzerinde kalan kirlerin uzaklaştırılması amacıyla gerçekleştirilmekte olup, sıcaklığın, mekanik hareketin ve sulu deterjan çözeltisinin bir arada kullanımını temel almaktadır. Gerçekleştirilen bu çalışmada yıkama işleminde kir çıkarma performansını etkileyen faktörlerden mekanik etki incelenmiştir. Çalışma kapsamında kurulan deney düzeneğinde, nozul sisteminden çıkacak suyun etki yüzeyinde oluşturacağı su jeti kuvveti; debi, etki yüzeyi ile nozul arasındaki mesafe, etki yüzeyi açısı ve nozul çıkış kesit alanına bağlı olarak deneyler gerçekleştirilmiştir. Deney sırasında ölçülen kuvvetler 0.09 ve 0.49 N aralığında değişmektedir. Aynı çıkış kesit alanına sahip nozulda debi arttıkça, suyun yüzeyde oluşturacağı jet kuvveti artmaktadır. Kesit alanı azaldıkça su jetinin uyguladığı kuvvet artmaktadır. Kuvvet üzerindeki baskın değişkenler incelendiğinde debi ve nozul kesit alanının etkisi sırasıyla %59 ve %21 mertebelerinde olduğu belirlenmiştir. Etki yüzeyinin açısının etkisi ise %19'dur. Etki yüzeyi ile nozul arasındaki mesafenin kuvvet üzerindeki etkisi sınırlıdır.
**Anahtar Sözcükler:** Mekanik etki, su jeti, jet kuvveti, etki yüzeyi, nozul, debi.

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## 1. INTRUDOCTION

Cleaning is the removal of dirt, soils, and any other materials from a surface. Cleaning performance, energy performance and amount of water affect each other. In cleaning process, increasing cleaning process is aimed without making any harmful effect on energy and water consumption.

Washing processes include chemical, thermal, mechanical effects and time to remove soils from a substrate. Chemical effect relates to chemical reaction used to remove or dissolve the soil from the work piece. Thermal effect relates to water temperature at which the chemical reaction takes place. Temperature also plays an important role in cleaning process when the soil to be removed, can be melted away or loosened by the effect of heat. The rate of chemical reaction can increase with an increase in temperature. Time is duration of force action in cleaning process; also it has an effect on other parameters (Tsouknidas and Zhang, 2010).

The mechanical impact which is studied in this paper as it relates to water jet force and flow of the spray leaving from nozzle. Water jet spray cleaning which uses droplets impact has been applied for removing contaminants from surface. When a water jet impacts to a solid surface at high speeds, the contact periphery expands very quickly and liquid compressibility plays an important role in the initial dynamics and the formation of lateral jets (Mccreery and Stoots, 1996). Mechanical effect of cleaning process is a function of the water jet impact angle, distance from nozzle to target, cross-sectional area of nozzle and flow rates.

Masuda et al. (1994) carried out surface cleaning by a high-speed air jet. A compressor supplied the air and a pulsed jet was achieved using an electromagnetic valve. Photomicrographs of the test piece were taken before and after the detachment experiments, and the number of styrene particles was counted by means of an optical microscope. The removal efficiency was calculated from the number of particles. The experimental conditions were between 15° and 45° impinging angle, between 3 and 25 mm distance from nozzles and the particle diameters between 1.09 and 11.9 μm.

It was shown that near the impinging point on the surface of the test piece, the removal efficiency was high and repeatability of the experiment was good. The optimum angle between the impinging jet and the surface was about 30º. The removal force acting on the particle was estimated from the kinetic energy of the jet, making it possible to explain the decreasing in the removal efficiency as the distance from the nozzle increased.

Sertore at al. (2006:2008) studied on water jet interaction on angled surfaces and measured force by a High Speed Rinsing (HPR) system. The experimental setup was based on a load cell, properly modified to withstand the wet environment of the HPR system, mounted at different positions from the nozzle to allow measuring the force at under various distances. The high purity water was used in this experiment and it was fed pressure pump able to supply 10 l/min at 100 bar. The high pressure filter was filtered and then sprayed by head mounting nozzles.

The angular dependence had been well reproduced in some cases. From these measurements they were calculated the total force of the jet. It was shown that the greater impact angles were provided a greater impact force with the same distances from spraying head axis to load cell. Besides, jet characterizations were imaged using the induced luminescence visible on glass targets. They were observed a clear and reproducible annular structure on samples placed at 35 mm from the axis. The structure was not observable at larger distances.

Wright et al. (1999) studied the performance of common, commercially available nozzle types under both poor and good upstream conditions. Variations in flow, pressure, standoff distance, traverse velocity and jet angle were compared. Flow conditioning methods such as vanes, screens and feeder tubes were evaluated for relative performance. The range of study was flow rates of 7.5 to 150 L/min, pressures from 35 to 105 MPa and standoff distances from 3.8 to 150 cm, corresponding to 50 to 200 nozzle diameters.

For removal of dirt from a soiled surface, one key parameter, being the force required to disrupt the deposit and remove it from the surface, is not known directly. Historically this parameter has only been determined indirectly, in terms of surface shear stresses inferred from pressure drop data or from correlation (Fryer and Slater, 1987).

Fouling deposits form as a result of adhesion of species to the surface and cohesion between elements of the material. At a macroscale devices such as the radial flow cell, which provide a range of shear stresses, have been used to study adhesion (Klavenes et al, 2002). On a smaller length scale, atomic force microscopy (AFM) has been used to characterize surface and fouling (Parbhu, Lee, Thomsen and Siew, 2002).

Ziskind et al. (2002) studied jetting angle effect on soil removing. There is an optimum angle to remove soil from a surface. 30° angle gives maximum soil removing performance. After this value, performance decreases.

Kibar et al (2010) studied hydraulic jump experimentally. The magnitude of the area of the spreading water layer decreases as the water contact angle of the surface increases. It also increases with the increase of the inclination angle, Weber and Reynolds numbers.

There are several factors that effect on cleaning performance. Thus, cleaning process was not identified as a standard simple mechanism. The present work is related with mechanical impact of cleaning processes.

## 2. EXPERIMENTAL STUDY

A schematic diagram of the Water Jet Test Apparatus is shown in Fig. 1. The experimental apparatus comprise a water nozzle, a set of impact surface, a dynamometer, a flow meter, a centrifugal pump, a water collection tank and plumbing for recirculating the water. Water was contained in a large tank consisting of a closed–loop water jet system, and the flow rate was adjusted with a valve and measured with flow-meter with a full scale accuracy of 1.0%. The average water temperature of the test was 25 °C. A high velocity jet is produced by the vertical nozzle. For clear observation, both nozzle and test plate are contained in a transparent cylinder. The water jet force was measured with dynamometer with resolution 0.1 N.

The pump sucks water from the collection tank and provides sufficient head for the water to flow through the flow meter and nozzle. The jet of water from the nozzle strikes to the impact surface. The dynamometer connected to impact surface with link beam, device allows measurement of the jet force necessary to deflect the water jet. The impact surface was connected to link beam with ball joint fitting for adjust impact angles between 0-90°.

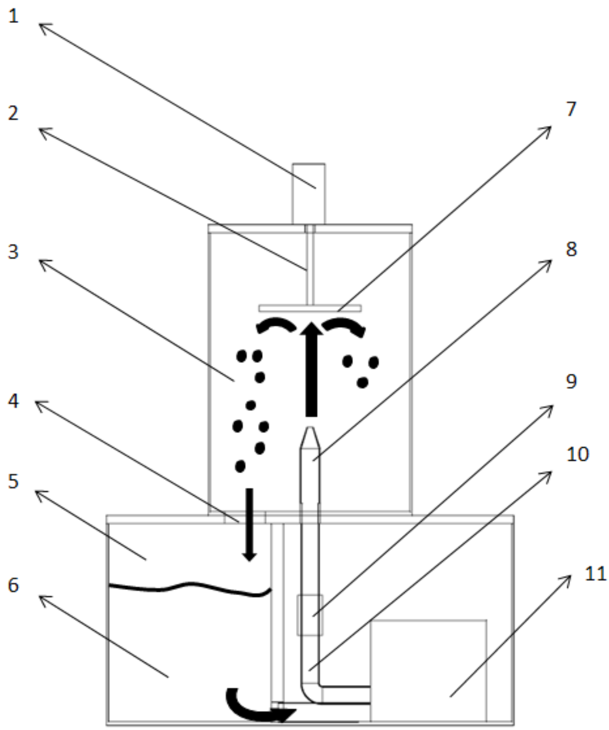


**Figure 1.** Water Jet Test Apparatus (1. Dynamometer, 2. Link beam, 3. Body, 4. Circulation hole, 5. Water collection tank, 6. Water, 7. Impact surface, 8. Nozzle, 9. Flow meter, 10. Plumbing for recirculating the water, 11. Centrifugal pump)

**Figure 2.** The impact surface with ball joint fitting to link beam

Tests are carried out according to experimental parameters that are given in the Table 1. Full factorial tests are realized thus effect of all parameters can be shown. The experiments are done with repetitive. Also center points are determined to see curvature. Curvature provides to know graph character between minimum and maximum values.

**Table 1.** Test Plan

| Parameters | Min Value | Max Value |
|---|---|---|
| Flow rate (l/min) | 2,5 | 3,5 |
| Cross-sectional are of nozzle ($mm^2$) | 11 | 17 |
| Impact angle (°) | 20 | 90 |
| Distance from nozzle to target (cm) | 15 | 25 |

## 3. RESULTS AND DISCUSSION

Water Jet Test Apparatus was used to measure force, generated by a jet of water as it strikes the surface under various experimental conditions.

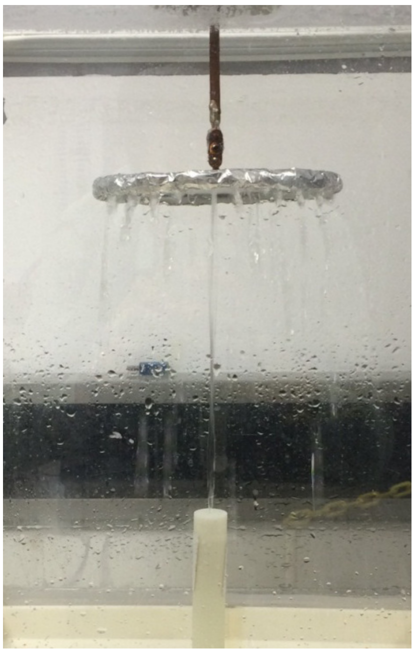

**Figure 4.** Water-Jet impacts on target

Fig. 4 shows the side view of the jet flow on a vertical impact surface. As shown in this figure, when a water jet was hit onto the target, the liquid sheet was tend to spread around the surface and then leaves from the surface

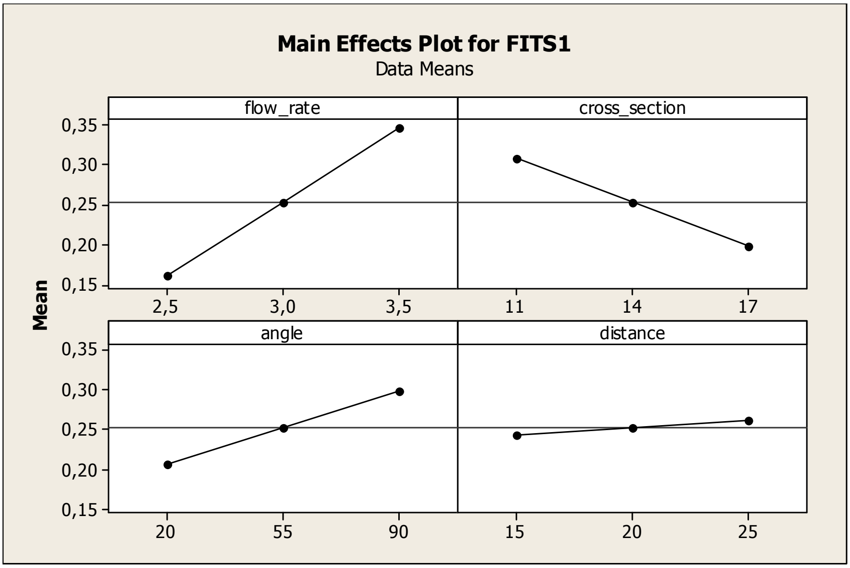


**Figure 5.** Main effects plot for parameters

Water jet impact force was a function of flow rates, angle of impact surface, distance from nozzle to impact surface and cross-sectional area of nozzle. The results showed that the higher flow rate provides a greater impact force with the same nozzle. If the cross-sectional areas of nozzles increase, the water jet impact forces decrease on similar flow rate values. For same experimental conditions, the jet impact force increases with angle of impact surfaces, reaches a maximum value on 90º. As seen in Fig. 5, the distance from nozzle to target increases for keeping the same experimental conditions, the measured value of jet impact increases slightly.

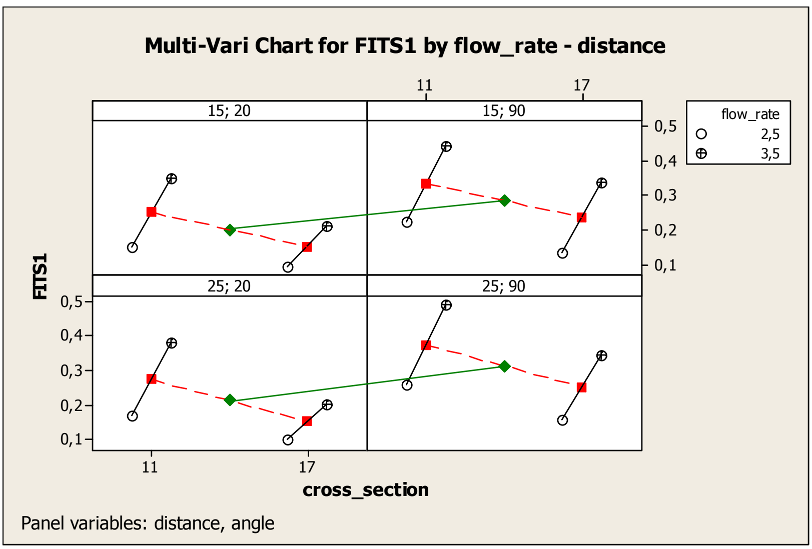


**Figure 6.** Multi variable chart for parameters

As a result of tests, the maximum water jet force was measured as 0,49 N when the volume flow rate was 3,5 l/min, angle of impact surface was 90°, the distance between the nozzle and the target was 25 cm and cross-sectional area of nozzle was 11 $mm^2$. The minimum force was measured as 0,09 N when the volume flow rate was 2,5 l/min, angle of impact surface was 20°, the distance between the nozzle and the impact surface was 15 cm and cross-sectional area of nozzle was 17 $mm^2$.

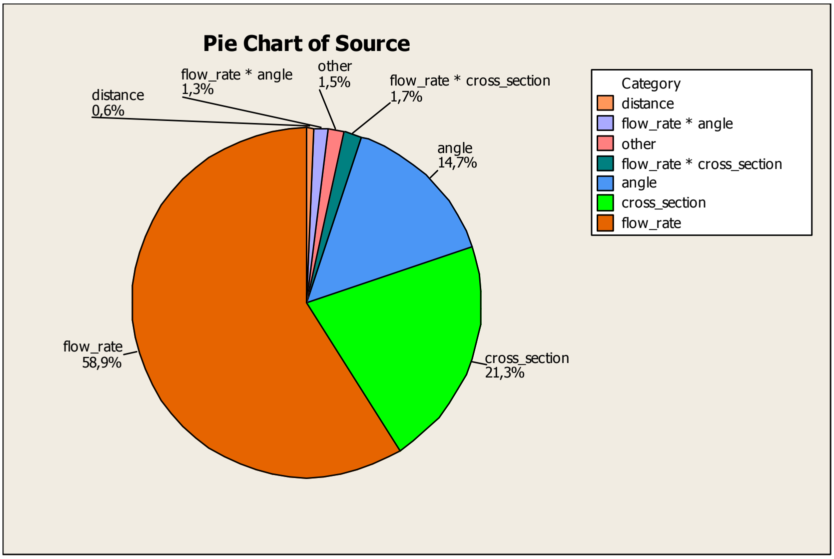


**Figure 7.** Pie chart of parameters

The model was obtained which it covers effect of parameters on jet forces 99%., it was shown in Fig 7. The most effective parameter on force was flow rate of water jet. As a result of tests, effectiveness of flow rate was 59%, effectiveness of cross-sectional areas of nozzle was 21% and effectiveness of angle of impact surface was 15%. The impact of distance from nozzle to surface had limited effect on the jet force.

## 5. CONCLUSIONS

Water jet impingement with three different nozzles, an impact surface, having inclination angles between 20° and 90°, different distances from nozzle to impact surface and under various flow-rates were observed experimentally and theoretically. From results,

- The most effective parameter on force is impact of flow rate. The second significant parameter is cross-sectional area of nozzles.
- Changes of impact angle and cross-sectional area of nozzle provide the great effect on high flow rates than low flow rates.
- The jet impact force increases with angle of impact surfaces, reaches a maximum value on 90º. It confirms literature results.
- The greater distance from nozzle to target provides a higher impact force. It is showed that the water jet is level of speed-up in 15 cm.

This paper is related with mechanical impact of cleaning processes. Flow rates, angle of impact surface, distance from nozzle to impact surface and cross-sectional area of nozzle play an important role in cleaning performance. They affect shear forces on soil removal process. We consider high water jet forces provide the greater removal efficiency. However, it is not the only effective parameter on cleaning process. Besides spreading of water on surface, types and roughness of the surface affect soil removal.

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