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AN EXPERIMENTAL STUDY OF EFFECTIVE FACTORS ON SOIL REMOVAL EFFICIENCY IN CLEANING PROCESS BY SOLID STREAM JET NOZZLES

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ABSTRACT

Cleaning is achieved by using cleaning agents and water to remove soil, rust stains, minerals or other deposits from surfaces. Following parameters affect cleaning performance: chemical factors, water temperature, cleaning time and mechanical impact on the surfaces. This paper is related with these impacts of cleaning processes. A Water Jet Test Apparatus was used to obtain soil removal efficiency, provided by a water jet as it strikes the dirty plate under various experimental conditions. Removal efficiency of treated plate was determined by image processing technique. The percentage of soil removal of soiled spinach samples were between 25.5 and 2.2, these were a function of flow rates, angle of impact surface, cross-sectional area of nozzle, water temperature, detergent concentration and exposure time. The results show that the higher flow rate provides a greater soil removal with the same nozzle. If the cross-sectional areas of nozzles increase, the removal efficiency decreases on similar flow rate values. For same experimental conditions, the cleaning performance increases with water temperature and cleaning agent concentration. The most effective parameter on soil removal was water temperature for spinach samples. As a result of these tests, effectiveness of water temperature was 32.2%, effectiveness of detergent concentration was 19%, effectiveness of volume flow rate was 10.7%, and effectiveness of cross-sectional areas of nozzle 3.6%. The remaining effectiveness of impacts was double and triple interactions. The impact of angle of jet impact surface and exposure time has limited effect on the soil removal for this experimental operating range.

INTRODUCTION

Cleaning is the process of using water and detergent to remove soil, rust stains or other deposits from surfaces. Cleaning performance, energy performance and amount of water affect each other. The aim of cleaning research is minimize the cleaning time and usage of cleaning agent without making any harmful effect on energy and water consumption.

Cleaning processes related with mechanical, chemical, time and thermal effect to remove soils from a substrate. The mechanical impact includes 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 [1]. 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.

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 together with an increase in temperature. Time is duration of force action in cleaning process; also it has an effect on other parameters [2].

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 [3]. 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 [4]. On a smaller length scale, atomic force microscopy (AFM) has been used to characterize surface and fouling [5].

Liu, Christian, Zhang and Frayer studied on cleaning process with micromanipulation technique for measure directly adhesive strength of food fouling deposits on a stainless steel surface. A T-shaped stainless steel probe was specially designed to pull fouling deposits away from a surface to which they were attached. Development of the technique has used tomato paste as a model soil [6].

Paste was baked onto stainless steel, and the effect of baking time, hydration time before cleaning and cleaning temperature studied. As a result of tests, strength increased with baking time and thickness of sample, and decreased with increasing hydration time and temperature. For this deposit, the cohesive strength was greater than adhesive strength at room temperature [6].

Masuda et al. 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 [7].

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 [7].

Wright et al. 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 [8].

A mixture of cement and sand were used as a target material. The volume removed was measured to determine jet effectiveness. The results showed that the deterioration increases with increasing flow rate. The effect of surface speed was dependent on standoff distance. At a 200 nozzle diameter standoff, the optimum was found to occur at or above 12 m/sec when multiple passes were made. At a standoff distance of 750 nozzle diameter, the optimum occurred with a single pass at 1.5 m/sec. The jet angle exiting the head between 45% and 135% affected jet quality up to 10 percent. However, performance differences of between 12 and 25 percent were seen depending on direction of travel over the surface relative to the jet angle [8].

Cleaning process is difficult to optimize, because of the lack of understanding of the ways in which surfaces clean and how they are affected by process variables. There are several factors that effect on cleaning performance. In this present work is related with mechanical, chemical, thermal and time effect of cleaning processes.

EXPERIMENTAL STUDY

Water Jet Test Apparatus

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 pump with heating device, 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%.

A high velocity jet is produced by the vertical solid stream jet nozzles. The water jet force is measured with dynamometer with resolution 0.1 N. The quantity of water was 10 liters which is heated a centrifugal pump with heating device for between 20-50 °C. For clear observation, both nozzle and test plate are contained in a transparent cylinder.

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 is connected to impact surface with link beam; device allows measurement of the jet force necessary to deflect the water jet. The impact surface which is shown that in Fig. 2 is connected to link beam with ball joint fitting for adjust impact angles between 0-90°. Test materials are connected to impact surface during the operation.

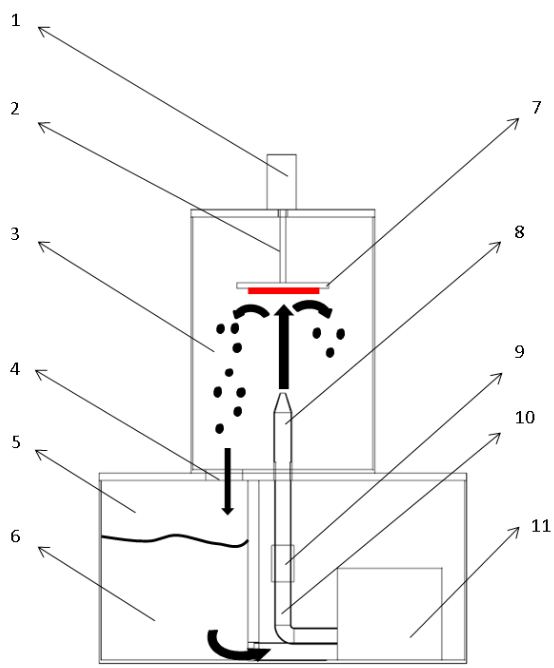

Fig. 1 Water Jet Test Apparatus (1. Dynamometer, 2. Link beam, 3. Body, 4. Circulation hole, 5. Water collection tank, 6. Water, 7. Impact surface (the red line indicates the soiled plate), 8. Nozzle, 9. Flow meter, 10. Plumbing for recirculating the water, 11. Centrifugal pump with heating device)

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

Before testing, uncertainty of measurement test was realized. Reproducibility and reproducibility of testing system was analyzed. Test system can recognize difference that born of different parameter's change on test. Also it gives repetitive results for the same inputs. Test system provides significant results according to uncertainty of measurement analysis.

Image Processing Technique

Image processing technique was used to analyze the visual results. It estimated how large a percentage of the soil particles area was cleaned during these tests. To provide high accuracy, series of analysis were done with a computer analyzing the dirty plates with spinach samples as it is shown in Fig. 3. This was done by scanning the plates with a high resolution scanner which is 600 dpi. Before and after cleaning, it was analyzed with numerical data. Then, measurement differences were showed that the soil removal efficiency.

Fig. 3 Test plates soiled with spinach

Test Parameters

Tests are carried out according to experimental parameters that are given in the Table 1. Half 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)	3	5
Cross-sectional are of nozzle (mm^2)	12	20
Impact angle (°)	20	90
Water temperature (°C)	20	50
Detergent concentration (g/l)	0	10
Exposure time (min)	10	20

RESULTS AND DISCUSSION

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

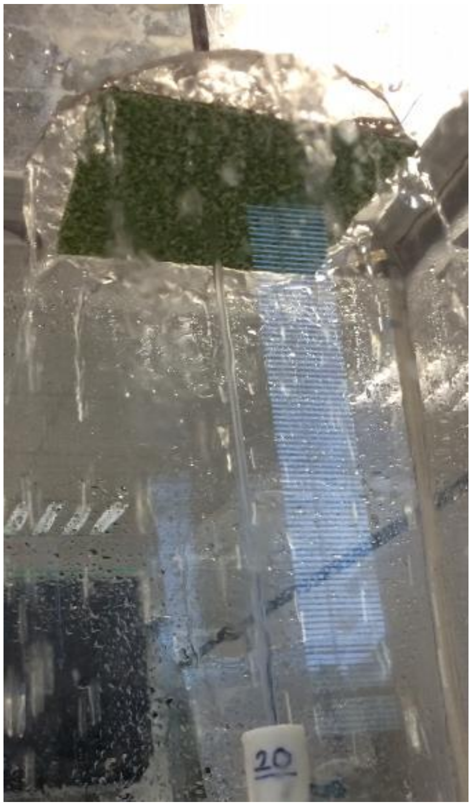

Fig. 4 Water-Jet impacts on target

Fig. 4 shows the side view of the jet flow on the 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, clean the plate and then leaves from the surface.

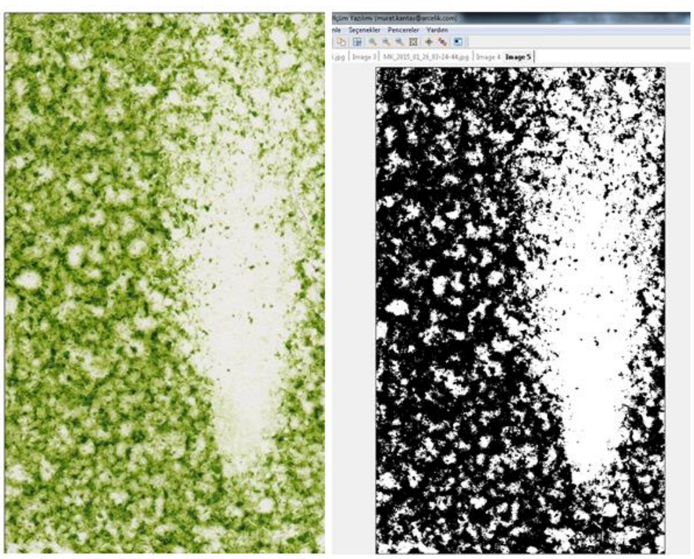

Fig. 5 Observation of treated spinach plate

Fig. 5 shows the treated soiled plate and analysis of this plate on the same image. The image processing analysis of the removed area was used to measure the average percentage of dirtiness which it was calculated from number of black pixels divided by number of total pixels.

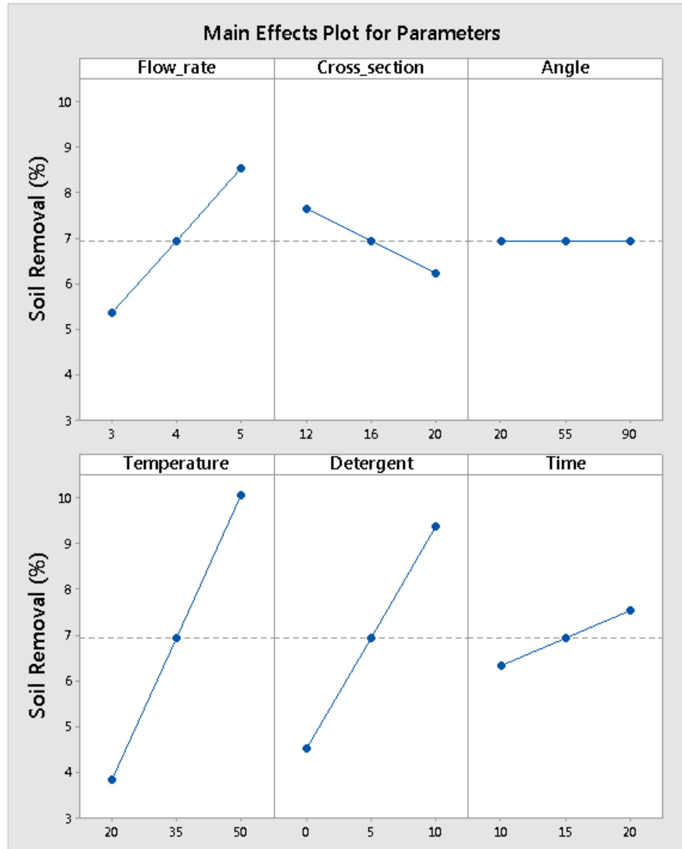

Fig. 6 Main effects plots for parameters

It was shown in Fig. 6, soil removal was function of flow rates, cross-sectional area of nozzles, and angle of impact surface, exposure time, water temperature, and detergent concentration. The results showed that the higher flow rate provides a greater soil removal with the same nozzle. If the cross-sectional areas of nozzles increase, the removal efficiency decreases on similar flow rate values.

For same experimental conditions, the cleaning performance increases with water temperature and cleaning agent concentration. As seen in Fig. 6, the exposure time from water jet increases for keeping the same experimental conditions, the measured value of soil removal increases slightly. But, angle of impact surface has not effect on the soil removal.

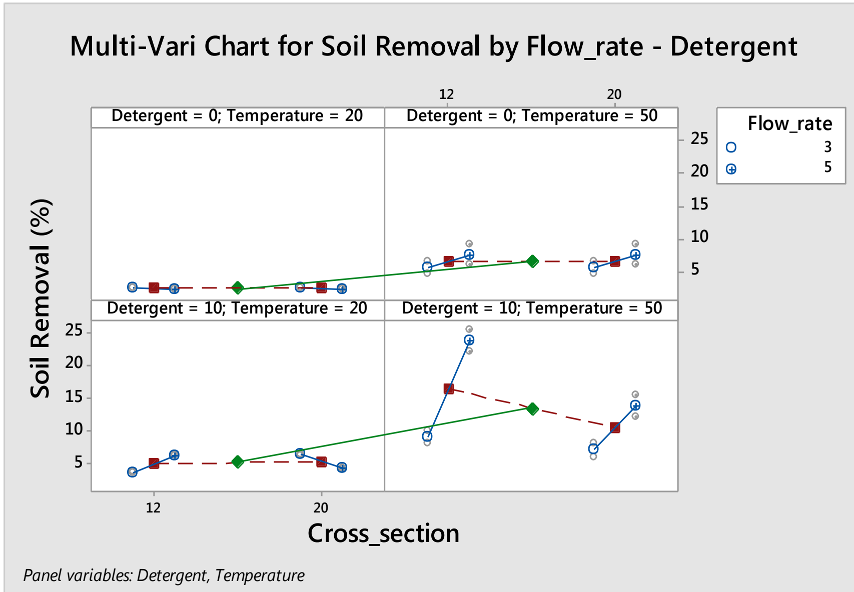

Fig. 7 Multi variable chart for parameters

As a result of statistical analysis, the maximum soil removal value was measured as 25.5% when the volume flow rate was 5 l/min, angle of impact surface was 20°, cross-sectional area of nozzle was 12 mm^2, exposure time was 20 minutes, water temperature was 50°C, and concentration of detergent was 10 g/l. The minimum soil removal value was measured as 2.2% when the volume flow rate was 3 l/min, angle of impact surface was 90°, cross-sectional area of nozzle was 20 mm^2, exposure time was 10 minutes, water temperature was 20°C, and there was no cleaning agent, it was shown in Fig. 7.

The model was obtained which it covers effect of parameters on cleaning process 92%, it was shown in Fig. 8. The most effective parameter on soil removal was impact of water temperature for spinach samples. As a result of tests, effectiveness of single water temperature was 32.2%, effectiveness of single detergent concentration was 19%, and effectiveness of single volume flow rate was 10.7%, and effectiveness of single cross-sectional areas of nozzles 3.6%. The remaining effectiveness of impacts was each of which double and triple interactions. The impact of angle of jet impact surface and exposure time had limited effect on the soil removal for this experimental operating range.

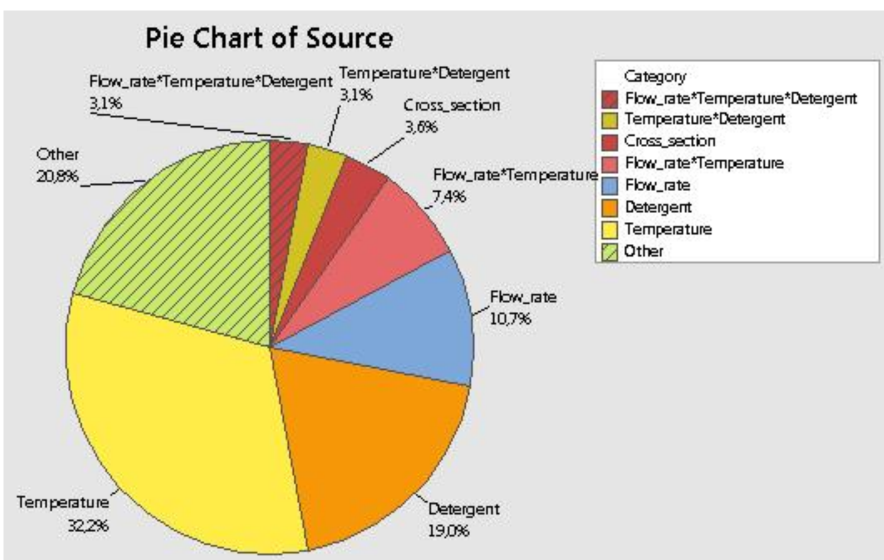

Fig. 8 Pie chart of parameters

CONCLUSION

Water jet impingement with three different nozzles, an impact surface, having inclination angles between 20° and 90°, different water temperature, detergent concentration, jet exposure time, and under various flow-rates were observed experimentally. From results,

- The most effective parameter on soil removal from spinach plates is water temperature. The second significant parameter is detergent concentration.
- The impact of angle of jet impact surface and exposure time had limited effect on the soil removal for this experimental operating range.
- A image processing technique using visual results, has been developed to measure the soil removal of food fouling deposits on the surfaces.

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 these impacts of cleaning processes. Flow rates, water temperature and detergent concentration of solution play an important role in cleaning performance for this operating range. They affect shear forces on soil removal process. We obtained effect of parameters on the soil removal efficiency of spinach particles from the surface. Besides all these, we consider spreading of water on surface, types and roughness of the surface affect soil removal.

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