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Separation System for the Treatment of Secondary Waste from the Waterjet-Abrasive-Suspension-Cutting

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Introduction

The water abrasive suspension cutting (WAS) is a technique used in the dismantling of nuclear facilities and has already been used to dismantle reactor pressure vessels (RPVs) and RPV internals. Components are cut using a high-pressure water jet and a sharp-edged abrasive. During the cutting process, a suspension containing abrasive and radioactive steel particles is produced. Presently, the entire particle mixture has to be disposed as so-called secondary waste generating high disposal costs.

In the research project MASK, a separation process for the post-treatment of this steel/abrasive particle mixture was developed to reduce the amount of secondary waste. By this post-treatment, the abrasive particles were separated from the particle mixture through a combined sieving and magnetic filtering process. A fraction of separated abrasive can be reused for further WAS-cutting.

Experimental and numerical investigations of the magnetic filter system and the sieving component has been carried out to improve the separation process. The following article describes the magnetic filter system in detail and explains its functionality with the help of numerical simulations.

Principle of the separation process

The aim of the separation process is to reduce the total amount of secondary waste by reusing abrasive particles for further WAS cutting, see Figure 1. A steel component, e.g. RPV or its internals, is cut by WAS during nuclear plant decommissioning. This produces a particle mixture of non-radioactive abrasive and radioactive steel particles (called the original steel/abrasive particle mixture, OM). OM consists of large, intact abrasive particles, smaller steel particles and abrasive fragments. In a first step, the fine particle fraction is separated by sieving. This fraction contains the major steel mass fraction and small abrasive fragments which have to be finally disposed. In a second step, the coarse fraction (CF) is separated from large steel particles with a magnetic filter. These large steel particles are also finally disposed. The remaining fraction of almost intact abrasive particles can be reused in the WAS process (reusable fraction, RF). A technical installation, the so-called MASK separation unit, is developed to demonstrate the feasibility of this process. The MASK separation unit is described elsewhere [1]. The present article focuses on the central part of the unit, the magnetic filter.

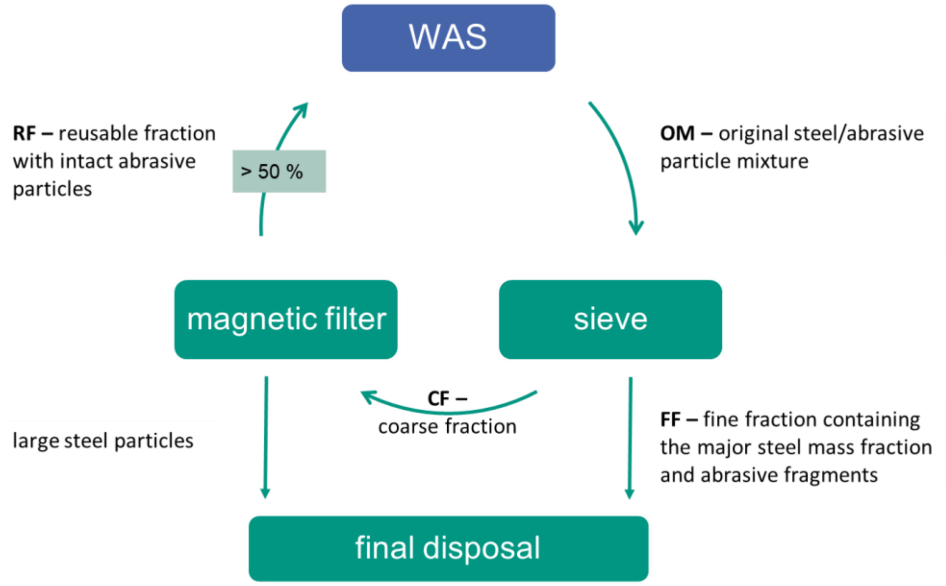

Figure 1: Principle of the reuse of abrasive and the separation process [1]

Magnetic filter

The magnetic filter and its main components used in the MASK separation unit is depicted in Figure 2.

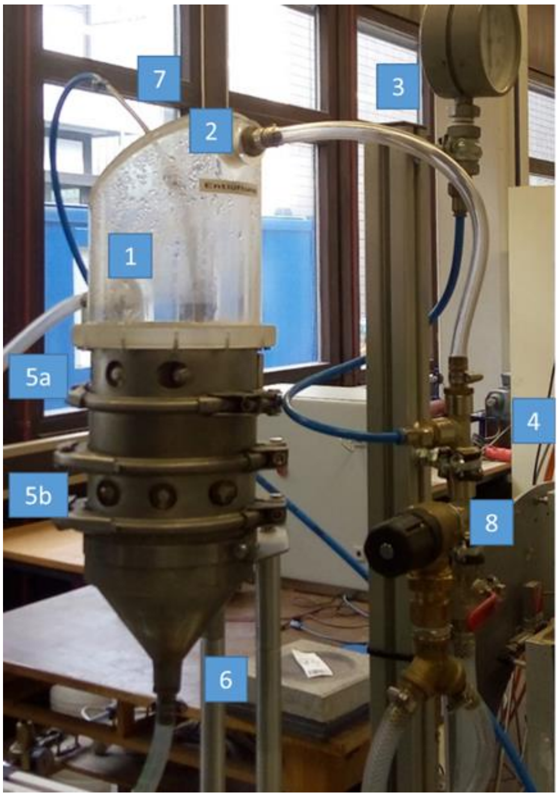

Figure 2: Picture of the magnetic filter, for details see text

Features of the magnetic filter are the inlet (1), the vent pipe (2), a pressure gauge (3), a cock (4), the two magnetic grids (5a and b) and a valve (8). The upper area of the magnetic filter is made of acryl glass as observation window of the experiment. The conus (6), is the outlet position, where the suspension leaves the magnetic filter. Compressed air can be injected via a pipe (7), which can be used to remove particles from the magnetic rods during the separation process. [2]

Figure 3: Left: Picture of the magnetic grid, right: Functional principle of the magnetic grid

The two magnetic grids shown in Figure 2 (position 5 a and b) are depicted in Figure 3. These magnetic grids are provided with the cladding tubes (1 in Figure 3) and the permanent magnets (2 in Figure 3).The magnetic filter is switched on and off by inserting or withdrawing the magnetic grids in the cladding tubes.

Computational fluid dynamic analysis

The investigation of the separation process of steel particles within the magnetic filter was done experimentally and numerically. A parameter defining the degree of separation was introduced. This indicated how much steel particles were separated during the magnetic separation process. It helped to determine the influence of two magnetic grids on the separation of steel particles.

A scheme of magnetic separation is shown in Figure 4 on the right side. A suspension of abrasive (black) and steel particles (green) enters the magnetic filter through the inlet. There, the steel particles are attracted to the cladding tubes by the magnetic field while the abrasive particles pass through the magnetic filter. For the investigations described below, the abrasive particles were neglected (see right side of Figure 4).

The degree of separation (A) is defined as follows:

$A = m_{MFS}/m_{A} * 100$

where m_A is the initial amount of steel particles and m_{MFS} is the remaining amount of steel particles in the magnetic filter after separation. The degree of separation is given in percent. Opensource programs like OpenFOAM, paraview, and salome were used for the numerical investigation of the magnetic filter. The magnetic field, the flow profile, and the particles inside the magnetic filter were simulated with OpenFoam. The visual analysis was carried out with paraview. In OpenFoam, an Euler-Lagrange model with a one-way coupling was selected for process investigation.

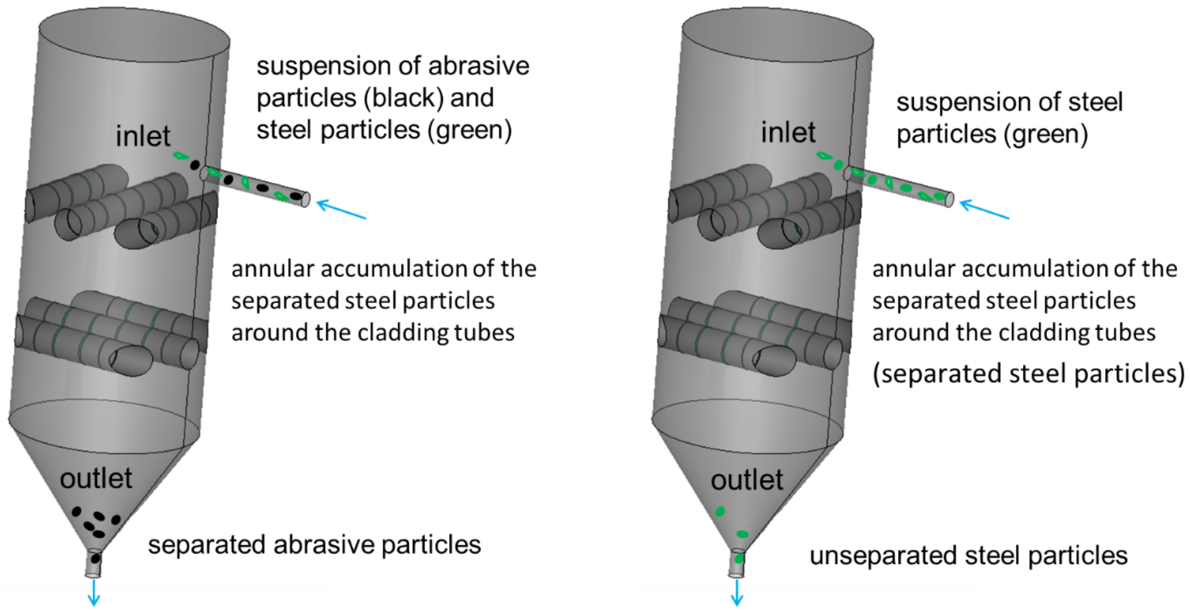

Figure 4: Left: Principle of magnetic separation, real; right: Principle of magnetic separation in the numerical investigations

Simulation of the magnetic field

Figure 5 shows a permanent magnet of the magnet grid. The structure consists of individual small, lined up permanent magnets. For a correct calculation of the magnetic field it is necessary to introduce a small gap between the individual permanent magnets. This small gap would also be present in the flow simulations where the fluid would flow through this gap. A different flow would be established than in reality.

Figure 6 shows that the steel particles mainly accumulate in zones where the magnetic field has a maximum (i.e., where two permanent magnets face each other). Steel particles accumulate concentrically around the cladding tubes. For the simulation, it is assumed that the particles are only attracted by a magnetic field in these zones. Figure 5 (above) shows the magnetic field of the simulation.

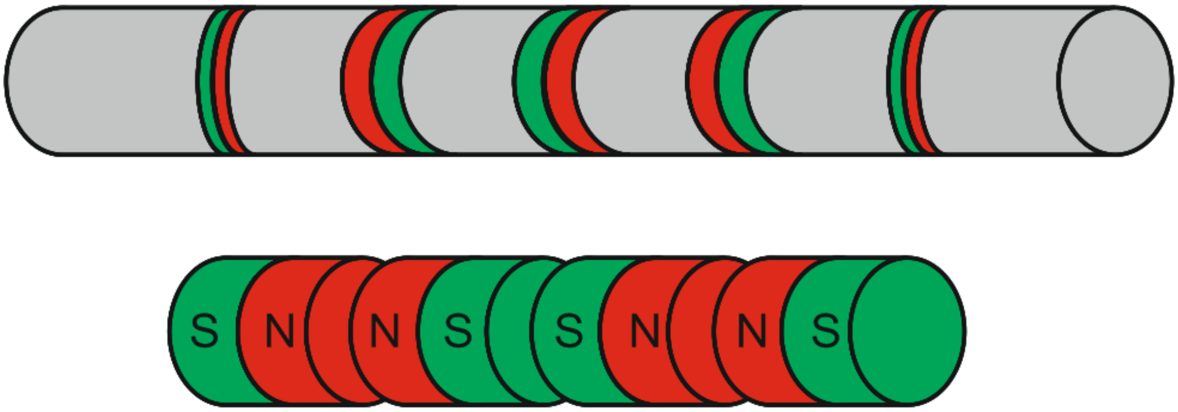

Figure 5: Above: Structure of the magnetic field in the simulation; below: Structure of a real magnet

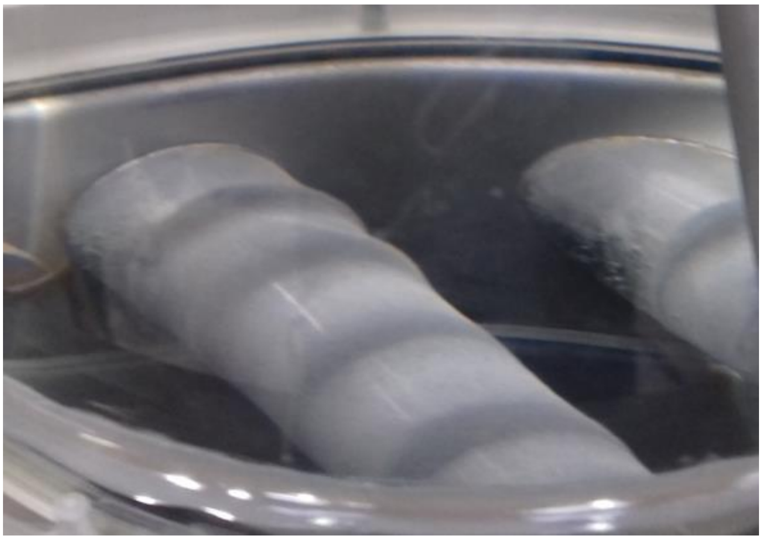

Figure 6: Accumulation of the separated steel particles around the cladding tubes

Flow simulation

The simple solver in simpleFoam was used to calculate the flow field. The k-omega model was used to model turbulence. The entry speed u was set to 1.8 m/s. The parameters k and Ω were calculated as follows:

$k=1.5*(I*|u|)^2$ and

$\Omega=k^{0.5}/(C*L)$

where the intensity I = 0.05, the constant C = 0.09 and L in this case is the inner diameter of the inlet pipe.

The results of numerical flow simulation coincide with the results expected. The result of incoming flow is shown in Figure 7. A turbulent pipe flow has developed in area (1) in Figure 7. A so-called impingement flow can be seen in area (2) in Figure 7. An impingement jet is shown in Figure 8, the flow field can be divided into three different regions. A free jet forms behind the nozzle outlet with increasing size because of mixing with surrounding fluid. As a result, the flow velocity decreases in direction of free jet. After a certain distance, the free jet changes into a stagnant flow where the vertical flow velocity decreases to zero. The horizontal speed component increases from this stagnation point up to a maximum value. This is followed by the area of the wall jet, which has similarities in terms of flow pattern to the free jet.

The flow pattern in Figure 7 reveals the jet with all properties of an impact jet. The simulated impact jet shows only one shift in z-direction. This is due to flow of surrounding fluid, where the flow direction within the magnetic filter is in z-direction.

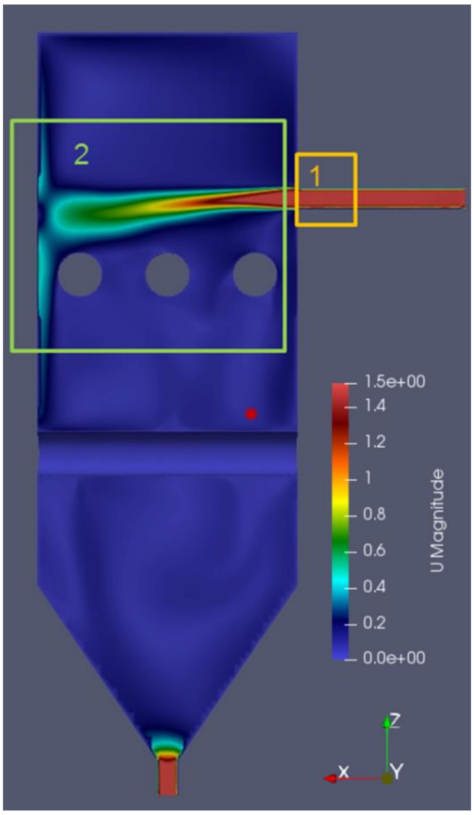

Figure 7: Flow in the magnetic filter: area 1: Turbulent pipe flow; area 2: impingement flow [3]

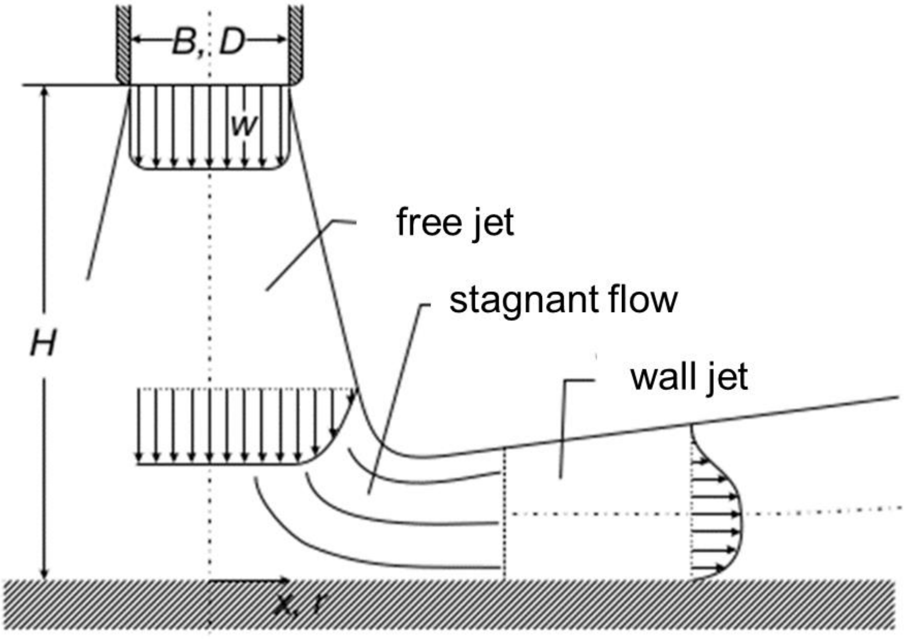

Figure 8: Impingement flow [2]

Particle simulation

The Euler-Lagrange model was used for particle simulation. Euler's view was used for the flow, i.e. the state of flow is a function of place and time. The Lagrangian approach was applied for particles, which is particle-fixed, i.e. the observer moves with the particle. Particle location and particle state are a function of time. A one-way coupling was used, i.e. only the continuous phase (flow) influences the disperse phase (particles). The solver icoUncoupledKinematicParcelFoam was used. With this solver, the flow, the magnetic attraction of the magnetic simulation and the gravity acting on the particles were studied. There are different ways to inject the particles. One of them is to write a file that defines the location of each particle. Since this is very time-consuming and error-prone with a large number of particles, a separate C++ program was written with particles homogeneously distributed within an area of the inlet. Figure 9 shows the magnetic filter and an enlargement of the inlet pipe in the area where particle locations are calculated. The program uses the density of particles, average particle size, and the concentration of the particles in this fluid area to calculate the particle locations. The resulting output can be read by OpenFOAM. The Rosin-Rammler distribution was used for the particle size distribution. A specially written program was used to determine the degree of separation (this parameter was defined at the beginning of the chapter). This program calculates the volume of particles inside the magnetic filter with help of a file issued by OpenFOAM in which the diameters of individual particles are listed. The degree of separation can be calculated with the initial and final volume. In this case, the degree of separation does not differ depending on the volume or mass of particles, as there is only one type of particle with same density. If the volume of the particles is used to calculate the degree of separation at the beginning of the simulation and at the end, a degree of separation A of 92% can be obtained. [2, 3]

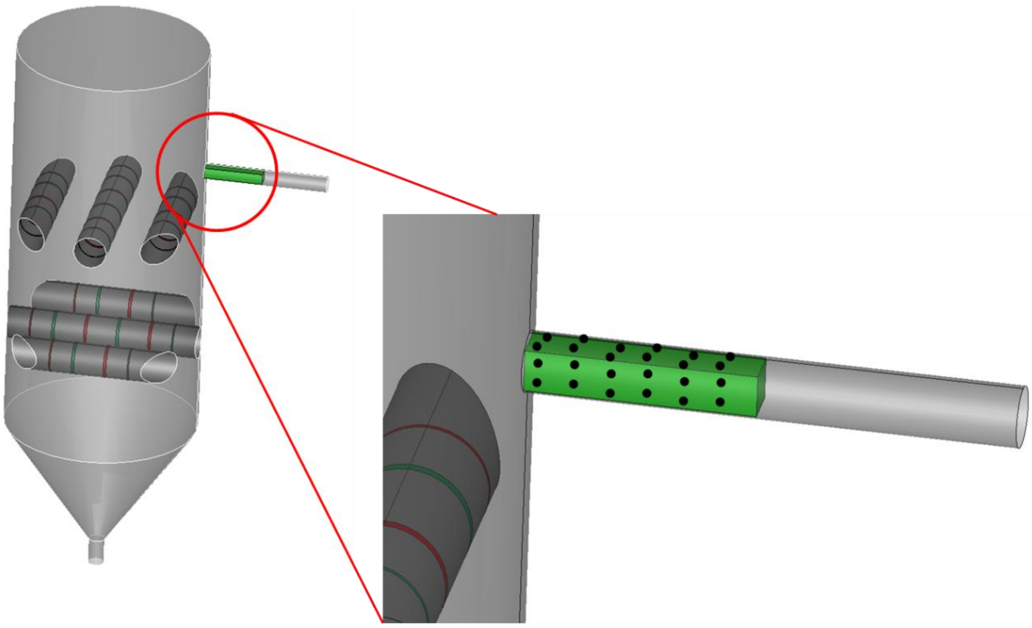

Figure 9: Illustration of the C++ program for particle location calculation

Conclusion

A separation process using a technical unit for treatment of a suspension containing abrasive and steel particles from water jet abrasive cutting of radioactive steel is presented. The purpose of this process is the reduction of waste volume by separation of steel particles and fragments of abrasive from reusable abrasive by sieving and magnet filtering.

A numerical simulation of the flow and attraction of steel particles by the magnetic filter was performed to optimize the separation process. The numerical simulation results indicate a removal of steel particles by the magnetic filter of 92 %.

In conclusion, more than 50 % of initial abrasive material can be reused for further cutting. Hence, a significant reduction of waste volume can be achieved.

Acknowledgment

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