5. Problem №6: Wet cleaning

5.1. *Solution of Czech*

Problem №6: Wet cleaning

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The Problem:

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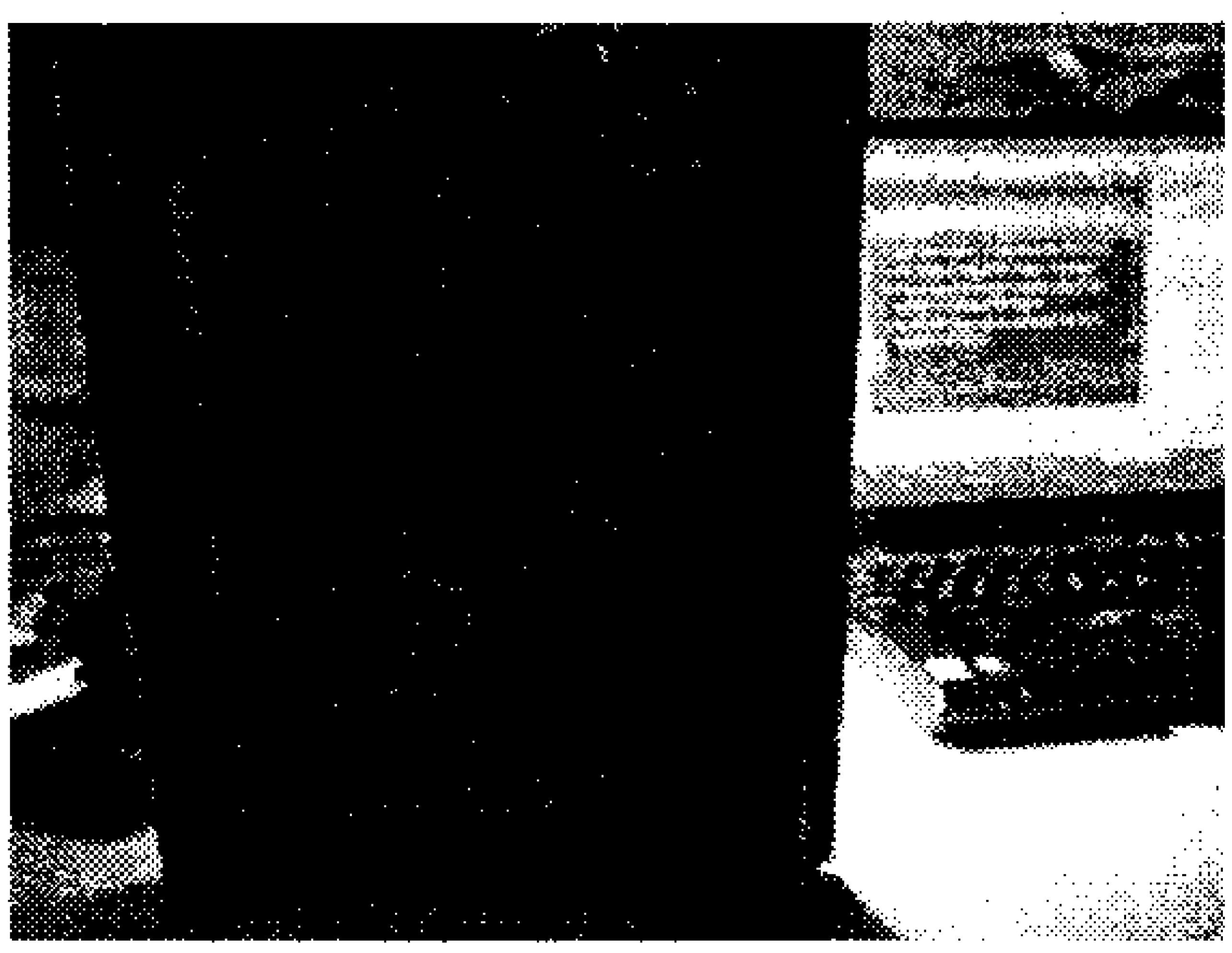
$$F_{od} = F_n \cdot f$$

A standard equation for the resistive force, where

m – total mass of wet rag

F_n – normal force (it is perpendicular to the underlay)

mostly caused by the gravity force of the pulled body, in our case, the normal force is not only the gravitational force. That can be demonstrated when we for example spread out a wet rag onto a small mirror which is held horizontally, afterwards we turn over the mirror. If the normal force was only the gravitational force, the rag would tear off and fall down but the rag can stay spread on the mirror (see fig. 1.) where the rag stays on a vertical surface.



-this phenomenon is mostly caused by the atmospheric pressure on the surface of the rag; the normal force could be therefore approximately expressed as:

$$F_n = m \cdot g \cdot \cos\alpha + p_a \cdot S \cdot \eta_{pa}$$

Where: -m – mass of rag

-g - acceleration of gravity

-α – inclination angle of underlay

-p_a – atmospheric pressure

-S – surface area of rag

-η – efficiency of the atmospheric pressure f –sliding coefficient

- its value would rapidly change with the volume of water contained in the rag
- like in standard cases, its value would depend on the roughness of materials of the underlay and rag
- however, less rough material does not have to induce a smaller resistive force. Sliding coefficient will decrease indeed, on the other hand, with the precision of the material, the efficiency of the atmospheric pressure on the rag will significantly increase because perfectly smooth surfaces will approximate to the effect of sticking two slabs of glass together with water (between them, all the air is squeezed out a slabs are stick together by the external force of the atmospheric pressure)

From our numerous experiments results also some certain dependence on so far not expressed physical quantities, e.g.: If we drag a rectangle-shaped rag at the shorter side and then at the longer side, will it be recognizable on the resistive force?

The answer is yes. By experiments, we have verified that the resistive force of the rag depends linearly on its width and depends radically on its length. In our equation, we have the area of the rag S, which is closely related with these parameters; therefore we have expressed our equation as follows:

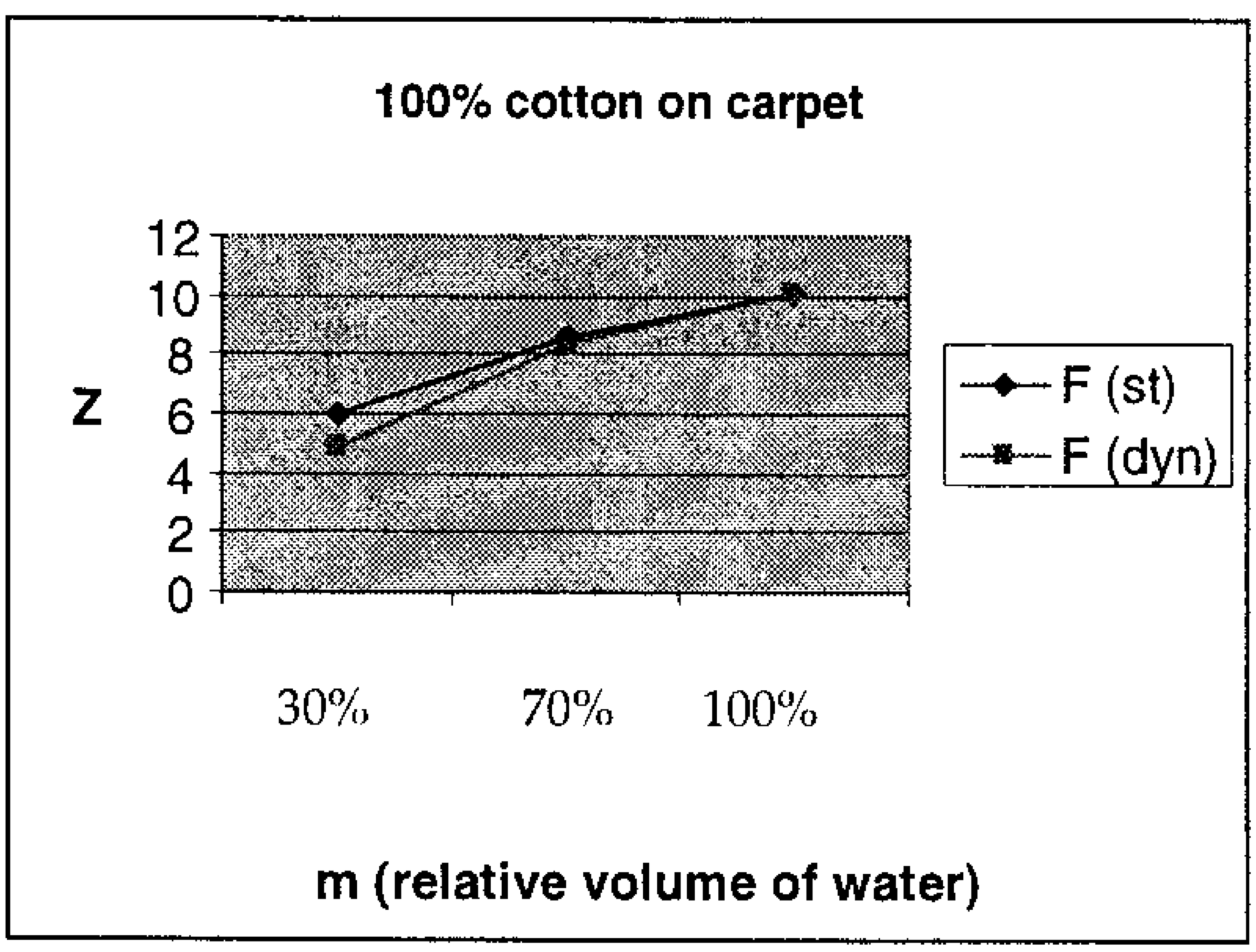
$$S = w \cdot \sqrt{l} \cdot \sqrt{t}$$

where: w – width of the rag
l – length of the rag
t – thickness of the rag

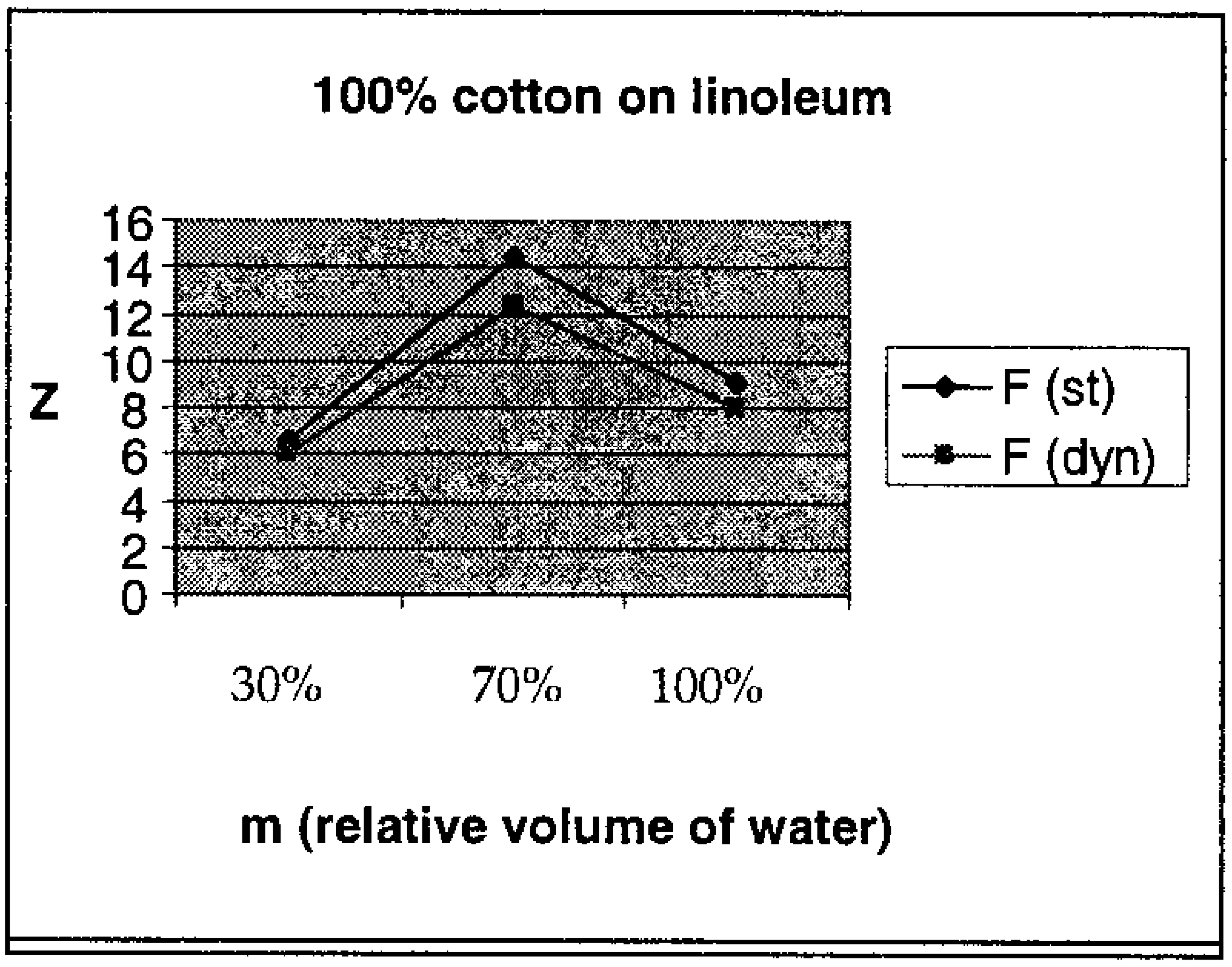
On the thickness of the rag depend more different forces in the wet rag and by its change, for example by folding the rag or simply using a thicker rag of the same material, we have proved that it is really a nonlinear, radical relation.

Efficiency of the atmospheric pressure was the most difficult to prove because in our conditions, we were unable to conduct experiments under different pressures and atmospheric fluctuations, regarding to accuracy of our equipment for force measuring (we used dynamometers pulled by tackle with by us estimated stable velocity measured by a ruler and a stopwatch) were so insignificant that we have not observed any changes.

We have already mentioned a phenomenon know as a two slabs of glass effect. Fine rag, in our case a synthetic rag, showed on smooth surfaces (where could be expected only a small resistive force) the biggest measured values of the resistive force.



This graph describes the change of resistive force at a constant velocity 0,2 m/s. The resistive force was measured using a 100% cotton rag by a movement of sweeping on a carpet. Values of forces in the graph are comparable to the standard cases. The only special phenomenon is the small differences between the dynamic and static resistive force.



This graph shows change of the resistive force of the same rag but on a totally different underlay.

Biggest values of resistive forces can be observed at a relative volume of water about 70%. At this volume, water does not flow out the rag but fill all pores and increases the normal force caused by an atmospheric pressure. At bigger values of relative volume of water, under the rag is formed a kind of a water pad and rag starts to slide on the water very easily and even at small velocities, a "aquaplaning" can be observed.

In the case of sweeping on a carpet, we have not observed this effect which was caused by absorbing redundant water by the carpet and by the presence of a big amount of air then also a nonzero pressure in the carpet. After these experiments, we have substitute in our equation the term of the standard pressure by a complicated term of a difference of atmospheric pressure and estimated pressure under the rag which was neglected in every experiment except the one with a carpet because before every measurement, we tried to squeeze out all the air under the rag and so get a approximately zero pressure under the rag.

After all edits, we got an equation as follows:

$$F_r = f \cdot (m \cdot g \cdot \cos\alpha + w \cdot \sqrt{l}\sqrt{t} \cdot (p_a - {}_{\phi}p_r) \cdot \eta_{pa})$$

Where: - f – coefficient decreasing with the volume of water in the rag

- m – mass of wet rag
- g – acceleration of gravity
- w – width of rag
- l – length of rag
- d – thickness of rag
- p_a – atmospheric pressure
- ${}_{\theta}p_r$ – average pressure under rag
- η_{pa} – efficiency of atmospheric pressure depending on smoothness of surface of the underlay, fineness of rag and on the volume of water inside the rag.