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An experimental study of the influence of liquid properties on the intensity of impregnation in magnetic resonance imaging

Industrial internship

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Purpose of work: Study the relaxation mechanisms for measuring the longitudinal and transverse relaxation times and imaging in papers.

Basis:

Nuclear magnetic resonance (NMR) is a physical phenomenon due to resonant absorption of electromagnetic energy. The phenomenon is based on a number of methods for studying the structure and properties of substances, physiology, chemistry, biology, geology, medicine and other areas of science and technology.

- Magnetic resonance imaging (MRI), which is based on the NMR phenomenon, is used to obtain images of the internal structure of various objects.
- High-resolution NMR spectroscopy and MRI require complicated and expensive equipment equipped with superconducting magnets. A distinctive feature of NMR relaxometry is the ability to measure relaxation times in relatively weak and inhomogeneous magnetic fields.

Equipments: Bruker Minispec and Bruker Biospec.

Bruker Minispec

$B_0 = 0.47T$

$\nu_0 = 20.01 MHz$

- diffusion coefficients
- relaxation time T1, T2

Bruker Biospec

$B_0 = 2.35T$

$\nu_0 = 100.05 MHz$

- imaging of large objects, porous media
- diffusion, dispersion

Bruker Avance III

$B_0 = 14.1T$

$\nu_0 = 600.33 MHz$

- micro-imaging
- diffusion, dispersion
- NMR in solid phase

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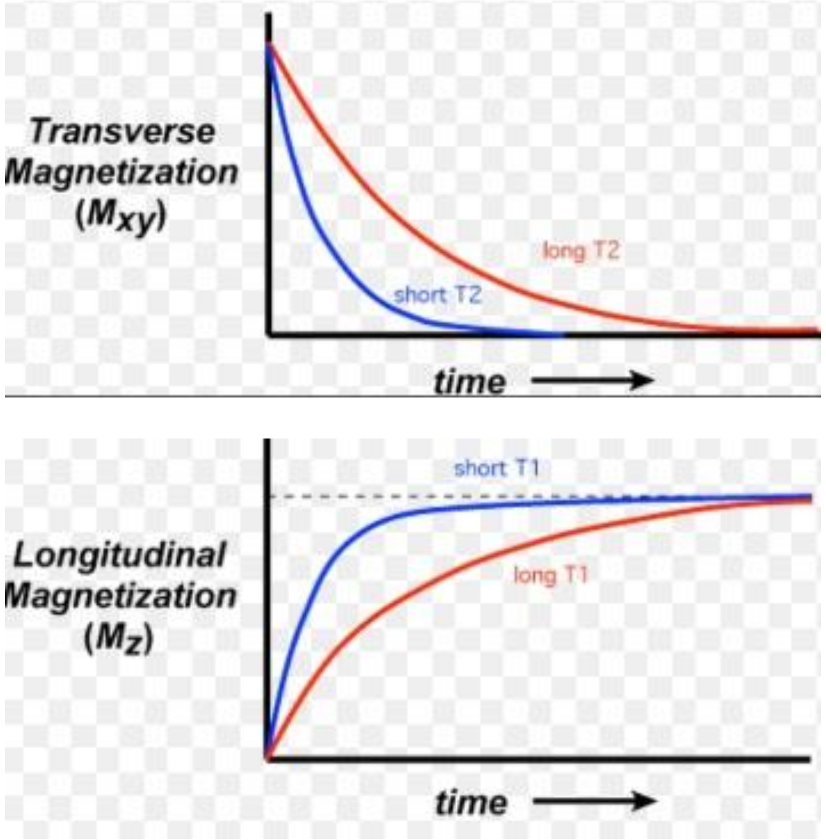
Short timescale wetting and penetration on porous sheets measured with ultrasound, direct absorption and contact angle

- The short-term penetration and spreading of liquids over porous sheets is investigated. Three measurement methods are evaluated: ultrasonic liquid penetration measurement (ULP), contact angle measurement (CA) and scanning absorptiometry (SA).
- For their research, they used model fluids with tunable surface tension, viscosity and surface energy, which are the control parameters of the pore flow in accordance with the Lucas – Washburn equation

Types of magnetic relaxation

- Spin-spin relaxation is also referred as transverse relaxation or T_2 and describes the decay of the excited magnetization perpendicular to the applied magnetic field.
- Spin-lattice relaxation is also referred as longitudinal relaxation or T_1 and describes the return to equilibrium in the direction of the magnetic field.



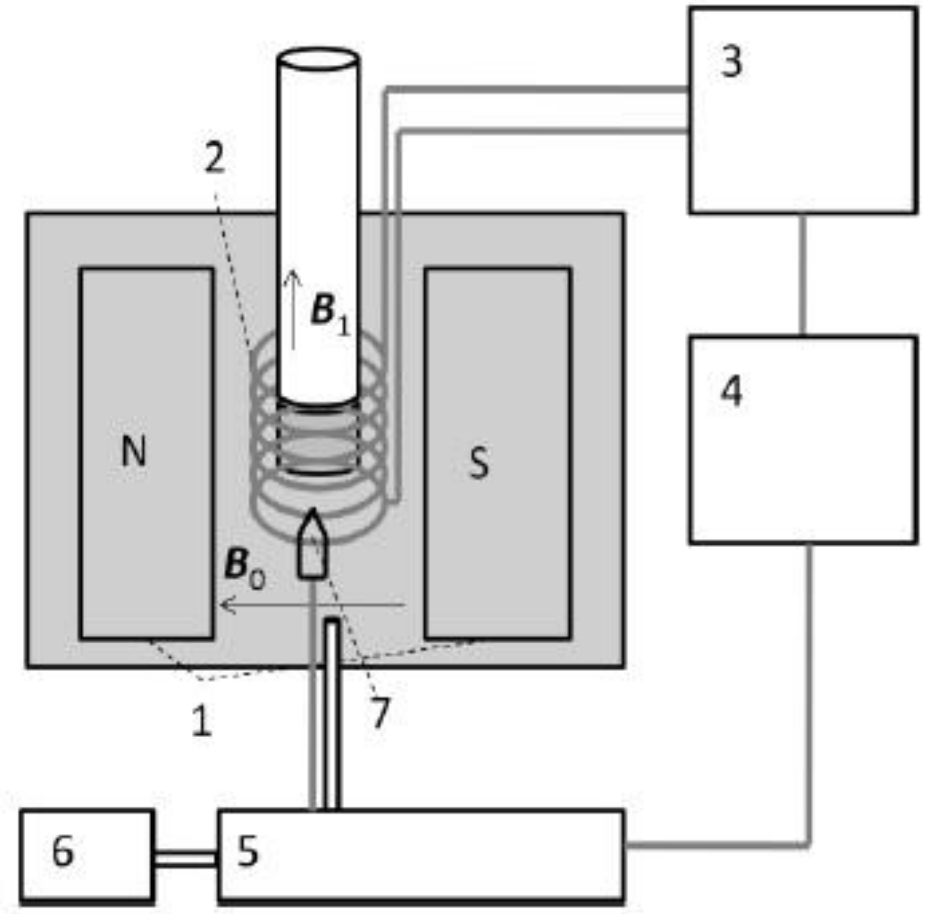
The main advantages of the NMR method.

- High resolution - ten orders of magnitude greater than optical spectroscopy.

- Ability to conduct quantitative accounting (counting) of resonating nuclei. This opens up possibilities for quantitative analysis of the substance.

- NMR spectra depends on the nature of the processes occurring in the test substance. And the timeline is available in a very wide range from many hours to small fractions of a second.

Schematic diagram of the NMR relaxometer.



The magnitude of the constant magnetic field strength of the Bruker Minispec relaxometer used in laboratory work is about 0.5 T. This intensity corresponds to the working frequency for protons ν_0 = 20 MHz.

1 - permanent magnet,
2 - inductance coil,
3 - pulse generator and radiation receiver,
4 - computer,
5 - sample temperature control system,
6 - air compressor,
7 – thermocouple

Testing papers

- We have 4 kinds of papers: AKD (alkyl ketene dimer) paper, UT (untreated) paper, UN (unsized) paper and PIG (pigmented) paper.
- All measurements have been conducted in a climate room under defined temperature (23 C) and humidity (50% relative humidity) according to ISO 187:1990. The papers were then stored in the climate room for at least 24.

Testing liquid and experiments

- Testing liquids. Twelve water based model liquids have been prepared with respect to their mass. The tested model liquids are: 100% water, 90% water/10% glycerin, 80% water/20% glycerin, 75% water/25% glycerin, 70% water/30% glycerin, 60% water/40% glycerin, 50% water/50% glycerin, 40% water/60% glycerin, 30% water/70% glycerin, 25% water/75% glycerin, 20% water/80% glycerin, 10% water/90% glycerin and 100% glycerin

Water with glycerin mixtures

Water with glycerin mixtures impregnated in paper

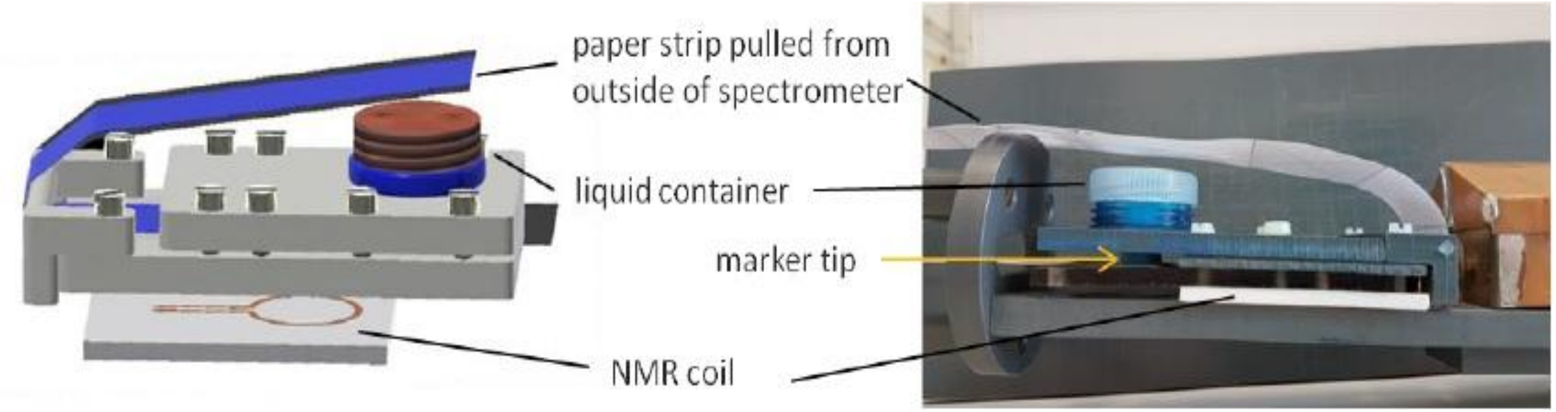
Experiment process

Find relaxation time T2 and T1 of liquid mixtures and T2 and T1 of liquid penetrated into paper.

Bruker Minispec

- 4 kinds of papers. In these papers we injected an ink.

Bruker Biospec



Experimental device

EXPERIMENTAL RESULTS

#	Liquid	mass (g)					liquid mass fraction c(%)
		tube	cap	paper	absorbed liquid	total	
6	Pure glycerin 100%						
7	Pure water 100%						
1	(UT paper) 100% water	8,0206	0,9045	0,268	0,3014	9,4945	112,46
3	(UT paper) 50% water/50% glycerin	8,061	0,9016	0,2285	0,3401	9,5312	148,84
4	(UT paper) 100% glycerin	8,0613	0,8972	0,2556	0,3439	9,558	134,55
4a	(UT paper) 25% water/75% glycerin	8,0002	0,9013	0,2153	0,3578	9,4746	166,19
5	(UT paper) 75% water/25% glycerin	8,0514	0,9011	0,2063	0,282	9,4408	136,69
7a	(UT paper) 10% water/90% glycerin	8,0281	0,9011	0,2135	0,3686	9,5113	172,65
8	(UT paper) 20% water/80% glycerin	8,0473	0,9058	0,2135	0,3692	9,5358	172,93
9	(UT paper) 30% water/70% glycerin	8,0369	0,9028	0,2099	0,3279	9,4775	156,22
10	(UT paper) 40% water/60% glycerin	8,0433	0,9038	0,2078	0,3062	9,4611	147,35
11	(UT paper) 60% water/40% glycerin	8,1129	0,9043	0,2121	0,3009	9,5302	141,87
12	(UT paper) 70% water/30% glycerin	8,0656	0,9037	0,2129	0,2883	9,4705	135,42
13	(UT paper) 80% water/20% glycerin	8,0376	0,9151	0,2118	0,2846	9,4491	134,37
14	(UT paper) 90% water/10% glycerin	8,0844	0,9041	0,2226	0,2725	9,4836	122,42

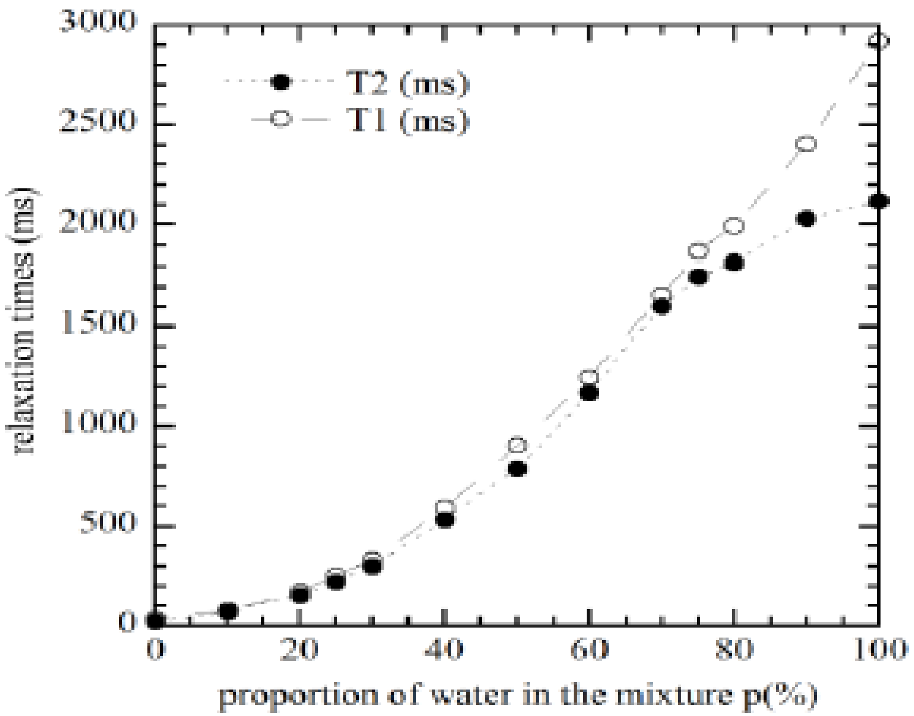
Mass of tube, cap, paper and liquid absorbed by the paper and mass fraction

Liquid mass fraction

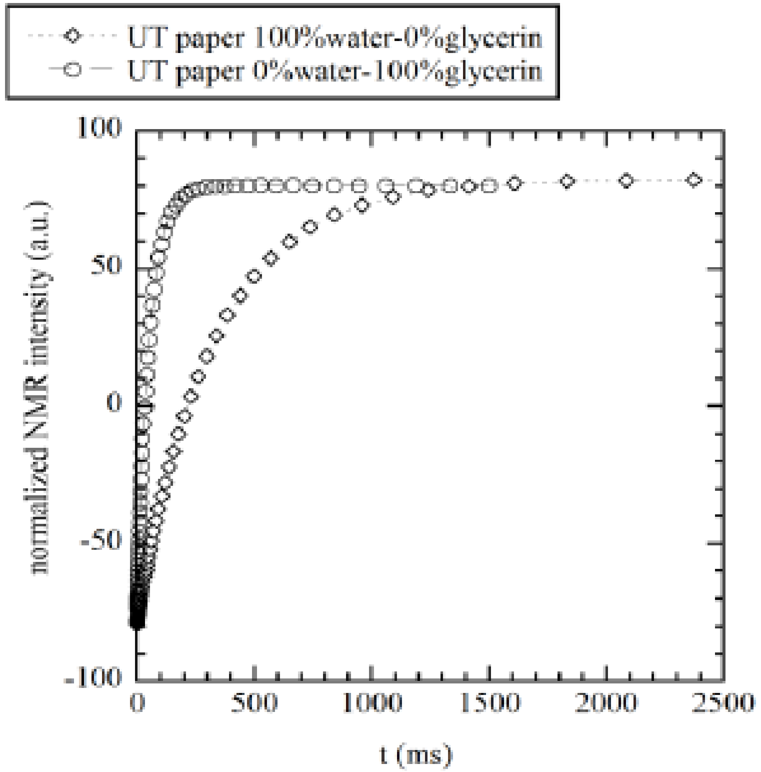
- We define the mass fraction c(%) of liquid introduced into a sample by the ratio $100 \times \frac{m_{liquid}}{m_{paper}}$, where m_{liquid} is the mass of the absorbed liquid and m_{paper} is the mass of paper (at room conditions). The mass fraction of water introduced into the sample containing only water c(%)=100*0.3014/0.268=112.46

tube number	water		t2	t1
7	100% water	100%	2117	2923
26	90%water/10%glycerin	90%	2029,5	2405
25	80%water/20%glycerin	80%	1814,5	1996
15	75% water/25% glycerin	75%	1746,1	1871
16	70% water/30% glycerin	70%	1602,8	1659
24	60%water/40%glycerin	60%	1168,5	1247,7
18	50%water/50% glycerin	50%	787,3	903
23	40%water/60%glycerin	40%	535,9	593
22	30%water/70%glycerin	30%	296,6	329
17	25%water/75% glycerin	25%	220	250,8
21	20%water/80%glycerin	20%	153,7	171,8
19	10%water/90%glycerin	10%	67,12	79,6
6	0% water	0	21,77	35,9

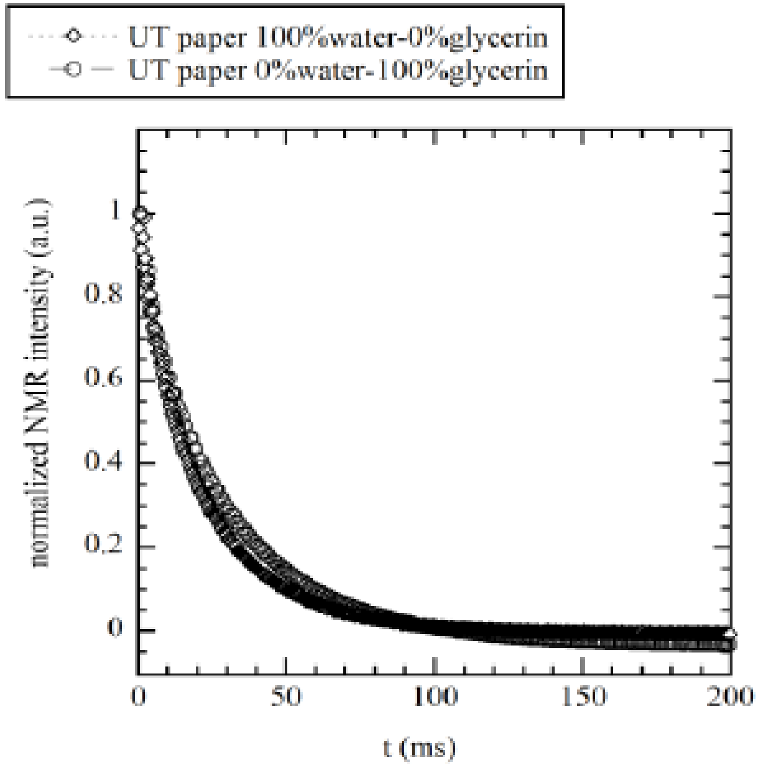
T2 and T1 of liquid mixture.



Proton NMR relaxation times of the water/glycerin mixture at 20 MHz and 25°C as a function of the proportion of water.

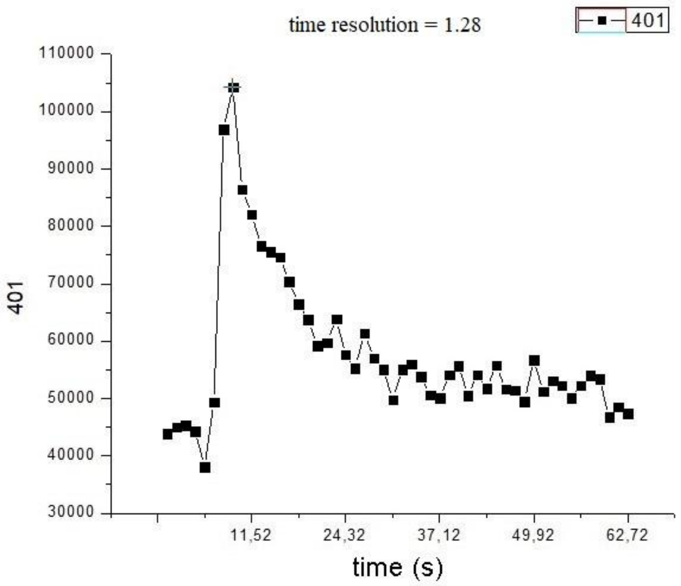


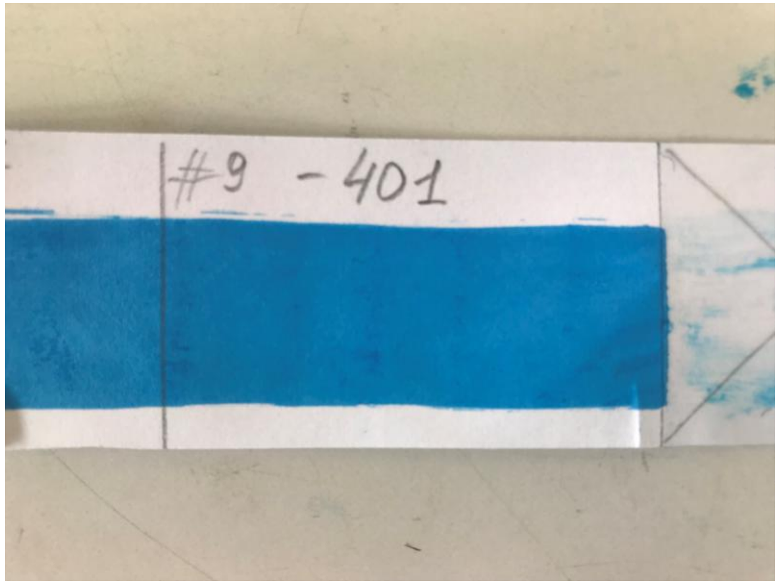
Evolution of the NMR intensity during an inversion-recovery sequence (measurement of the T_1 relaxation time) in the two cases '100% water in UT paper' and '100% glycerin in UT paper'.

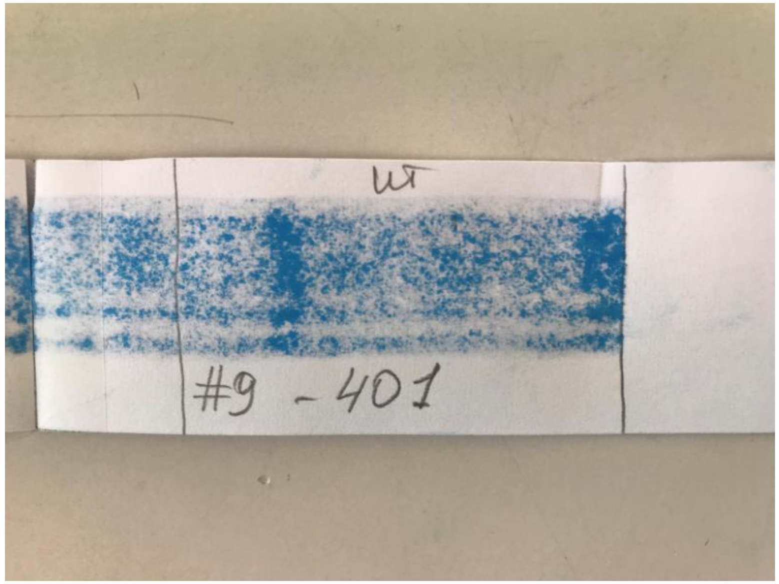


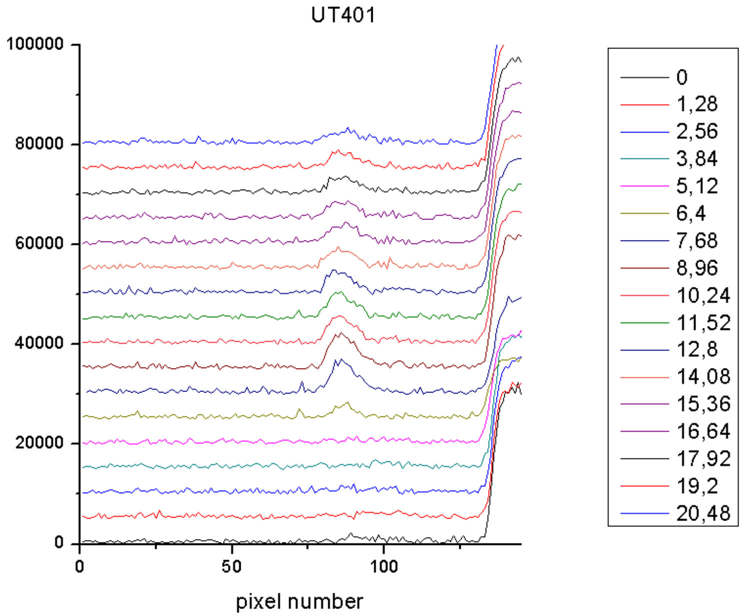
Evolution of the NMR intensity during a CPMG sequence (measurement of the T_2 relaxation time) in the two cases '100% water in UT paper' and '100% glycerin in UT paper'

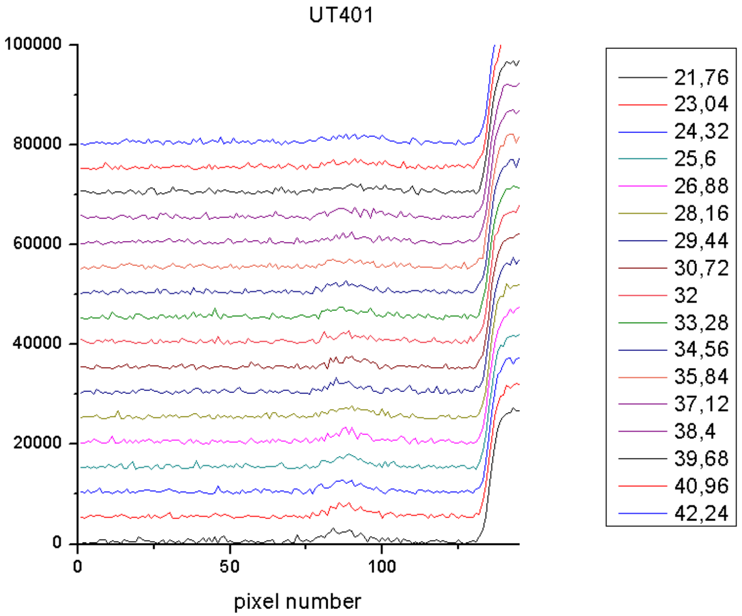
UT paper #9-401

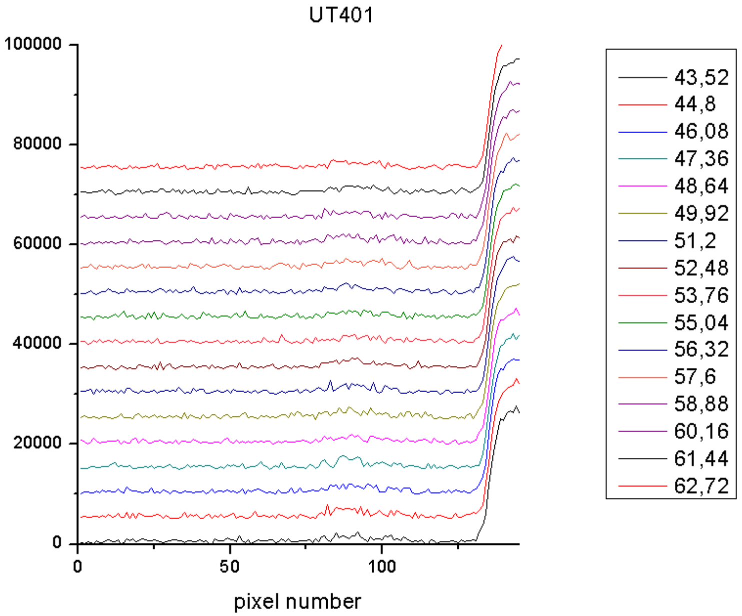




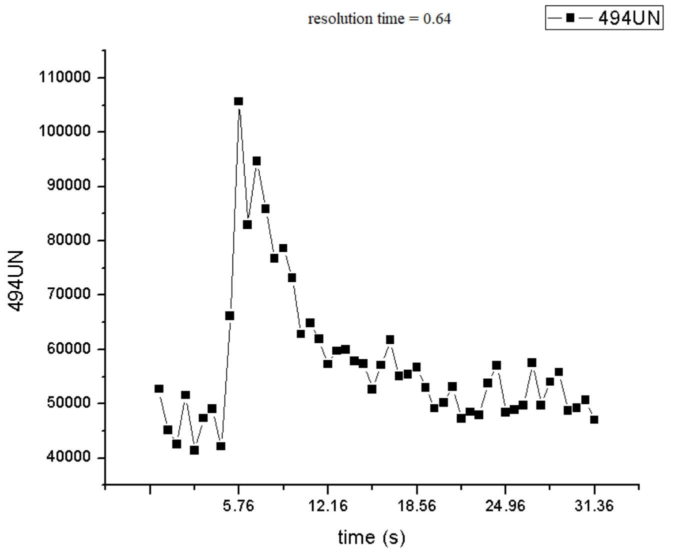


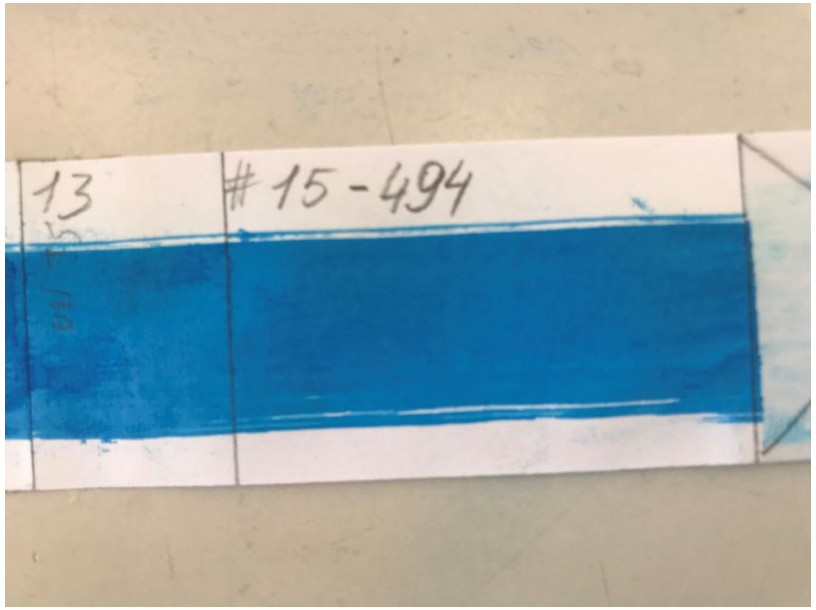


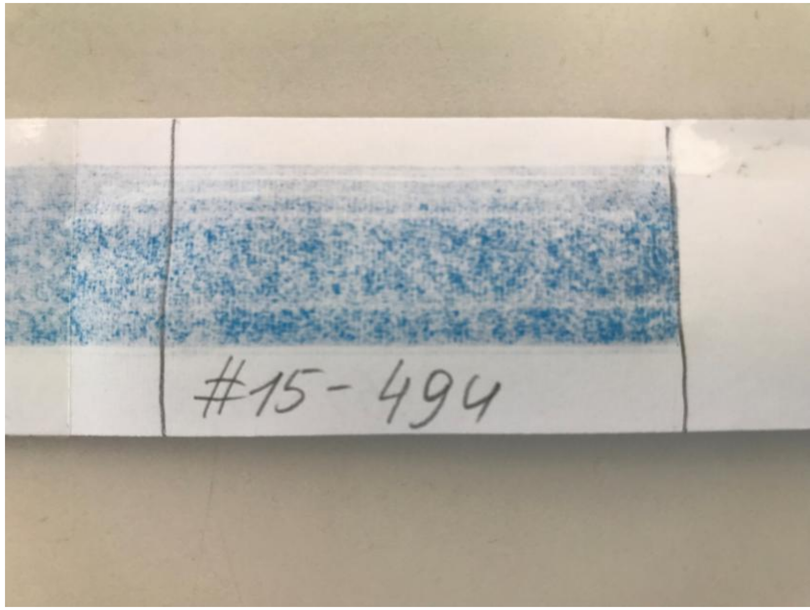


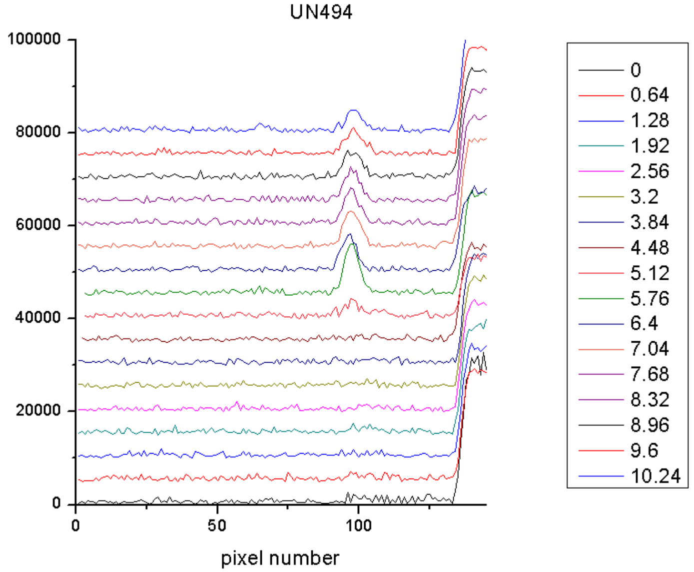


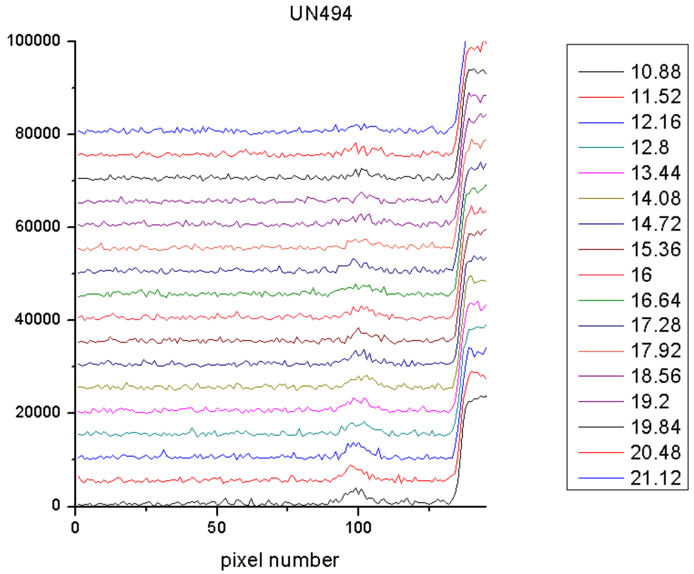
UN paper #15-494

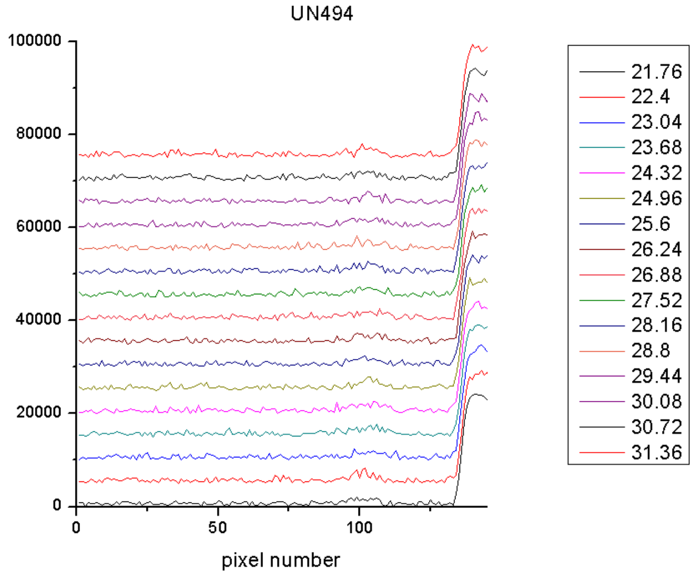




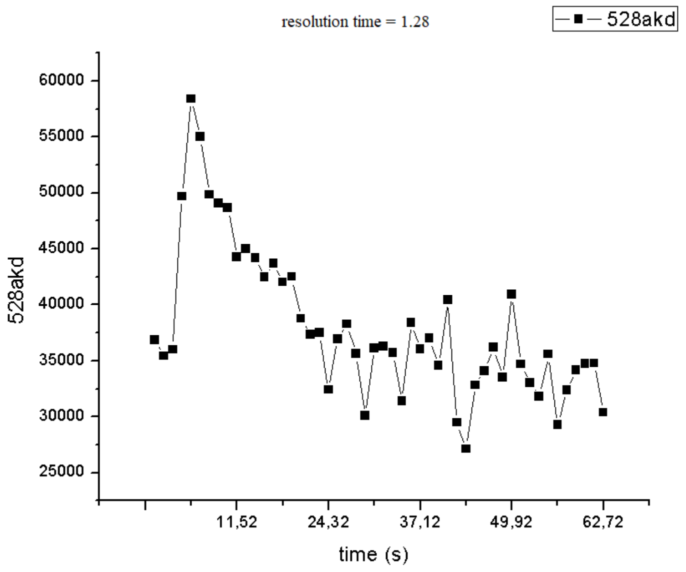


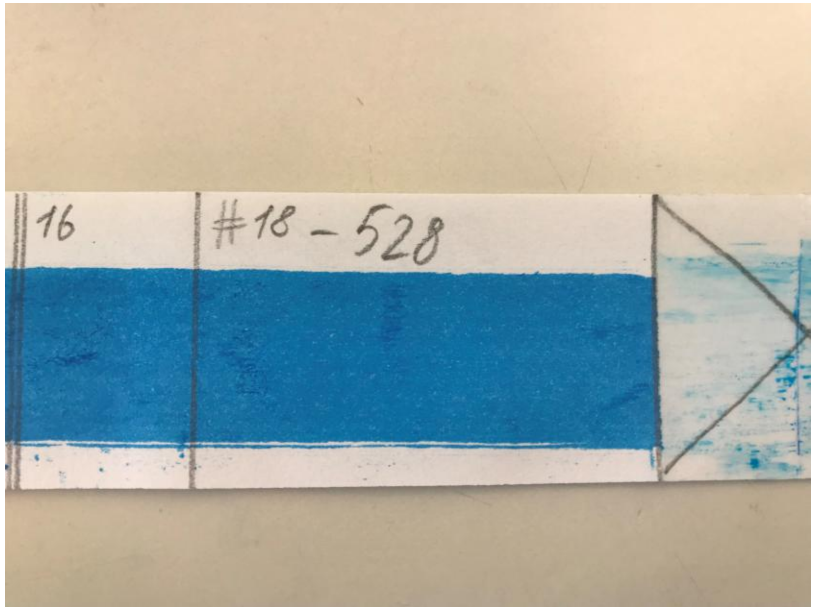


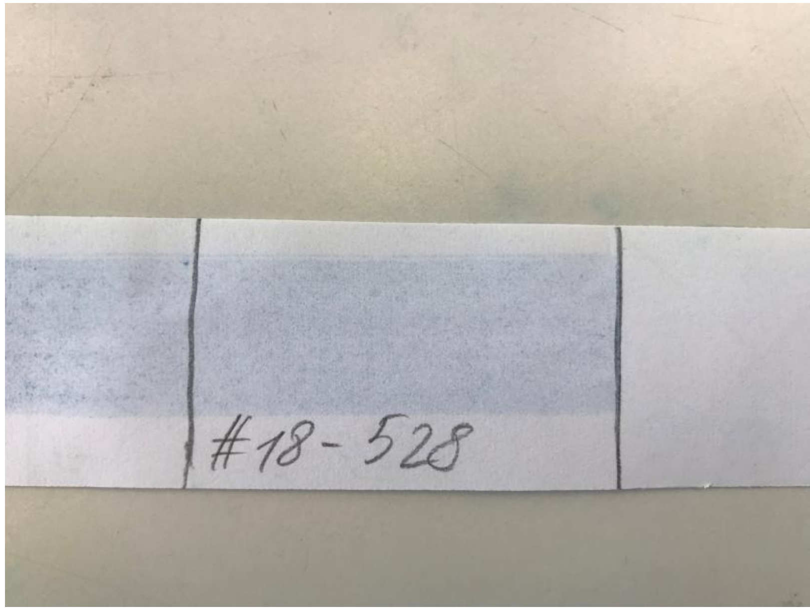


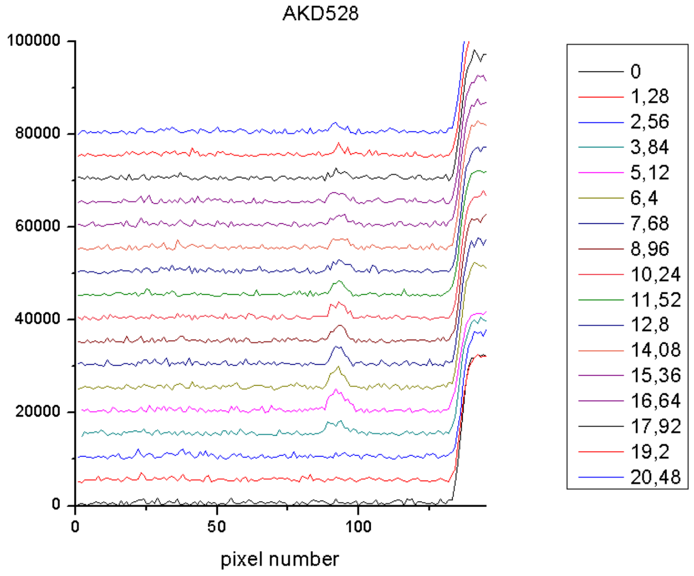


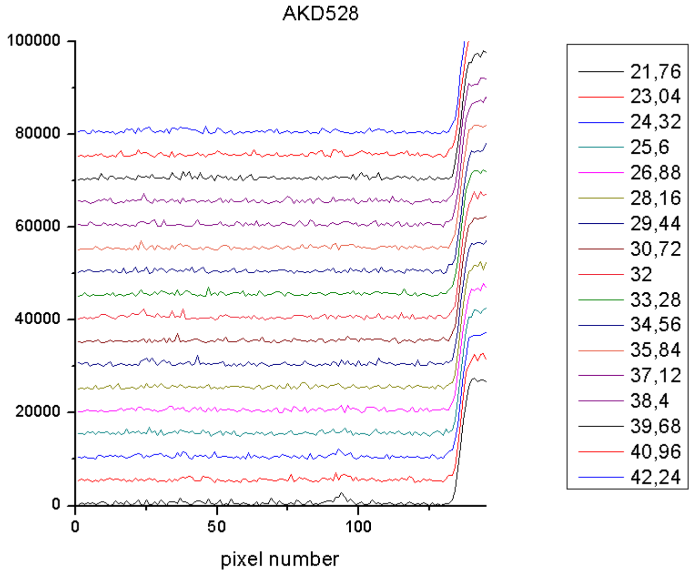
AKD paper #18 - 528

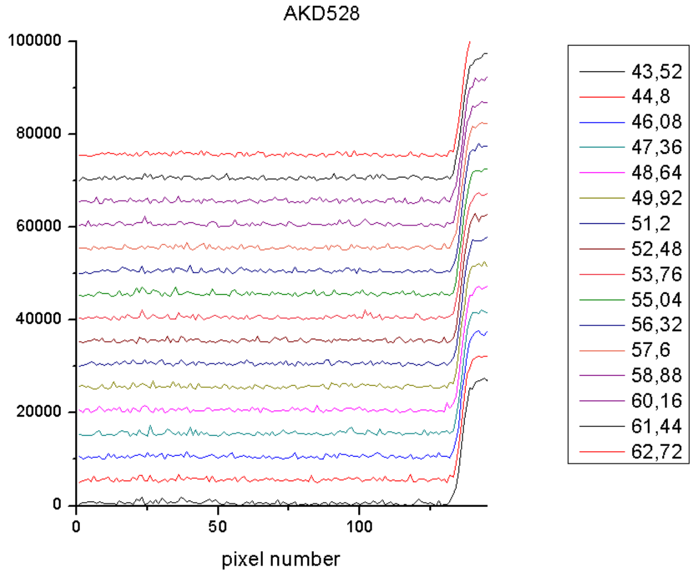




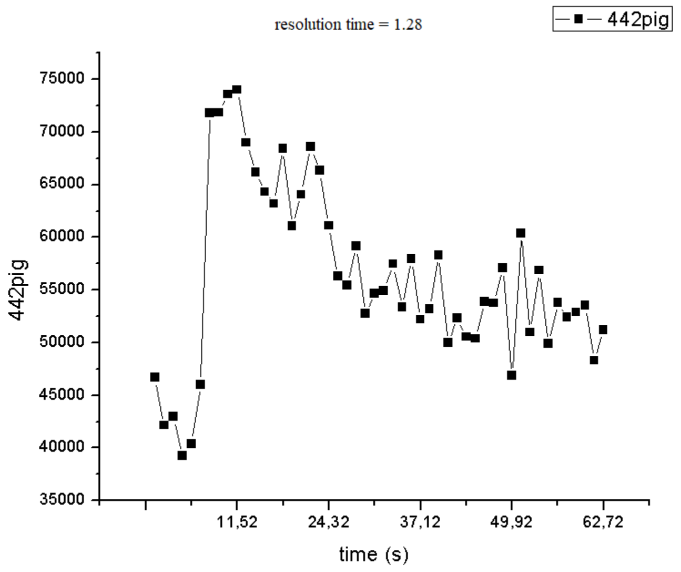


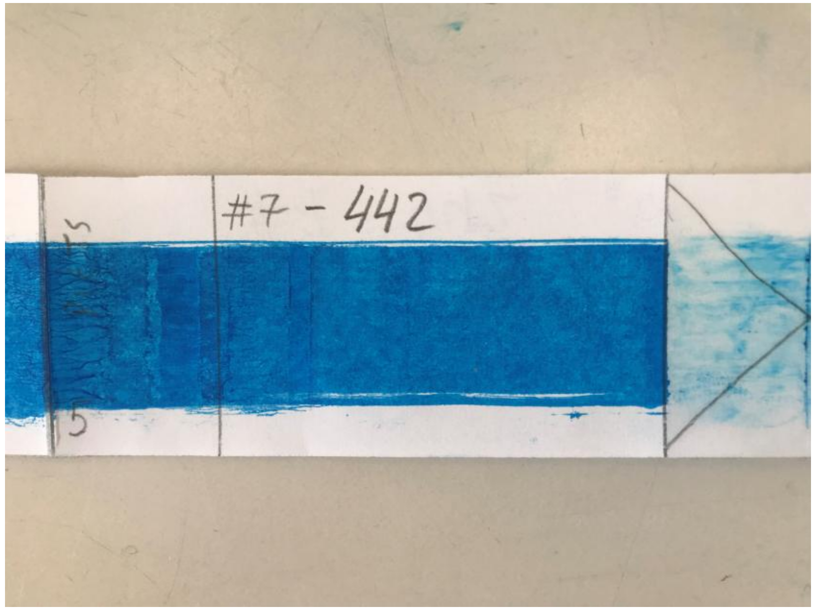


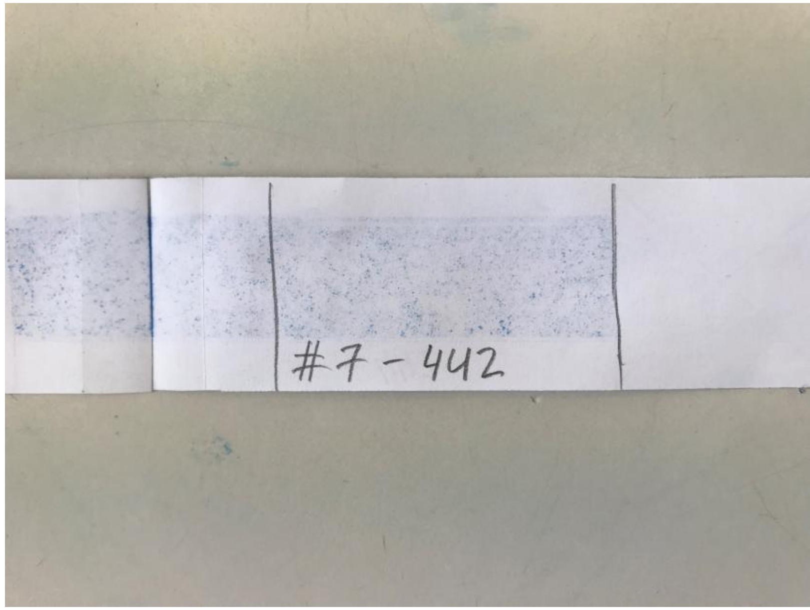


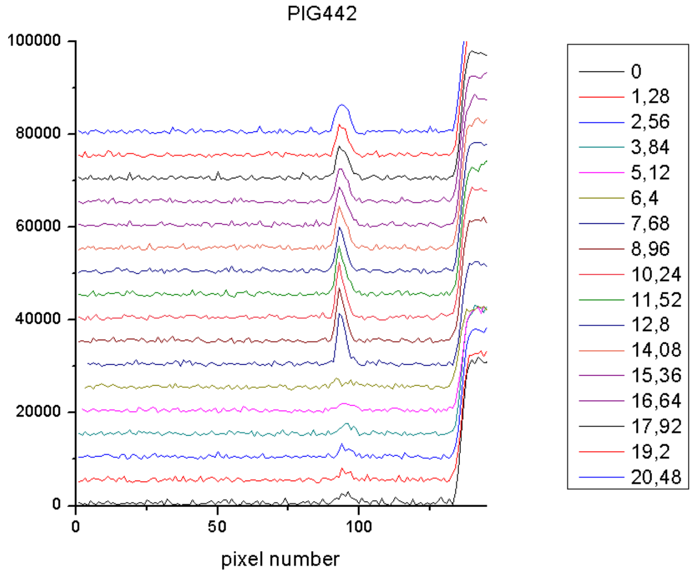


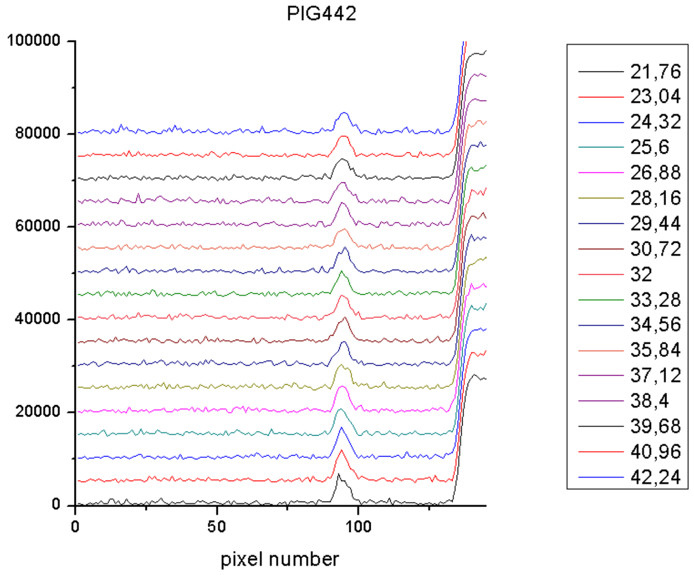
PIG paper #7-442

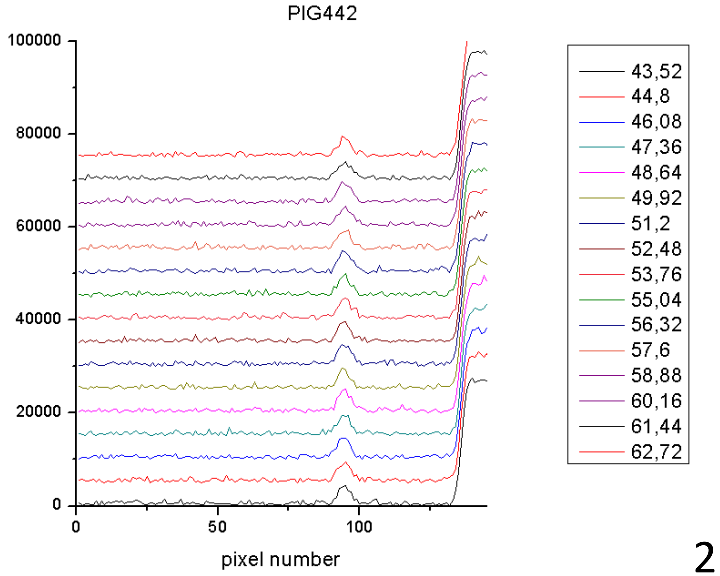




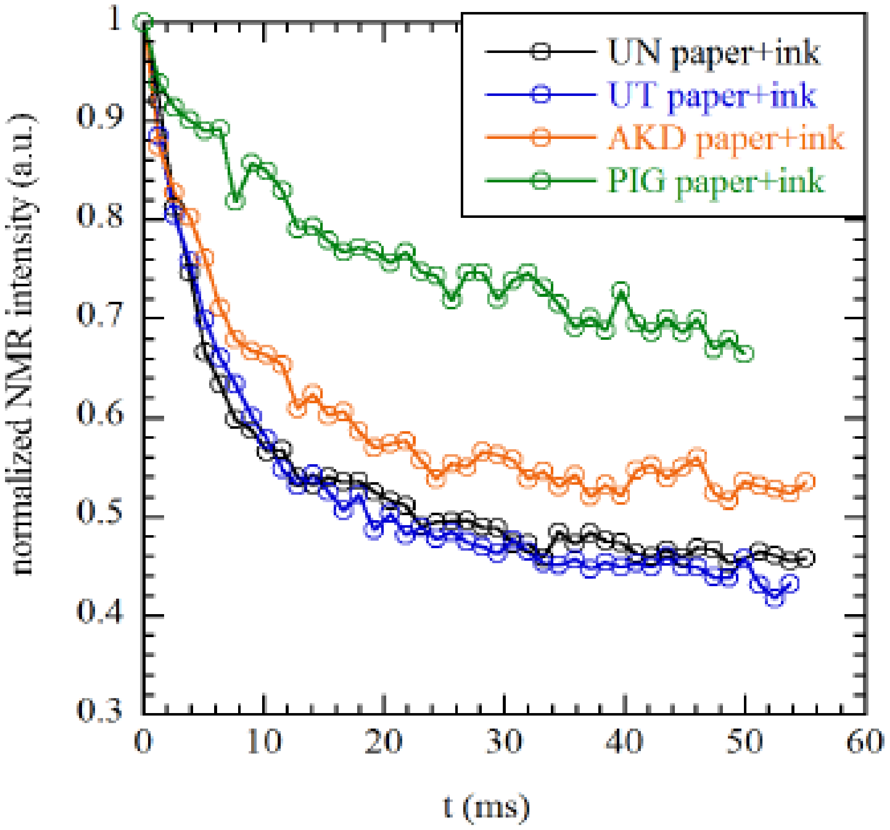








The time evolution of the integrated NMR intensity tells us how the aqueous phase of the ink dries once it has penetrated the paper. In the Untreated and Unsized papers the signal disappears quickly while it takes much more time in the AKD and even more so in the PIG paper. The distance over which the ink penetrates is also smaller in PIG paper than in any other specimen.



Temporal evolution of the integrated NMR intensity after the application of ink at the surface of the UT, UN, PIG and AKD papers.

NMR imaging of water penetration in paper.

The same experiments have been performed with water instead of ink. The behavior is about the same in every cases and every type of paper:

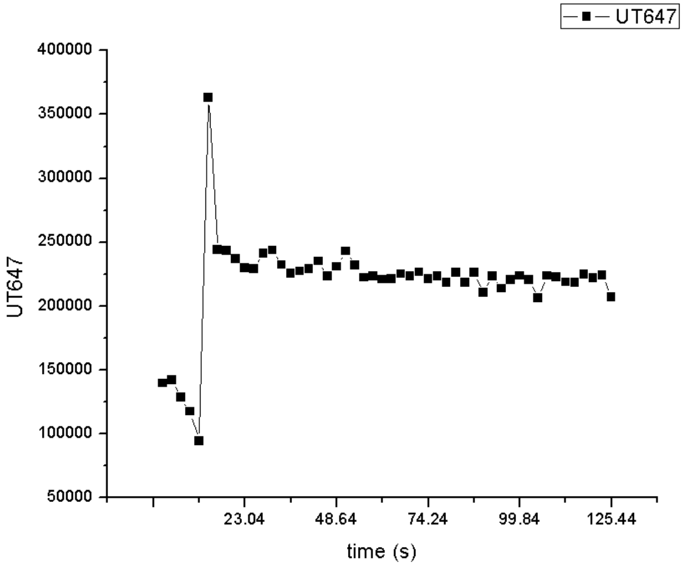
- the penetration is very fast;

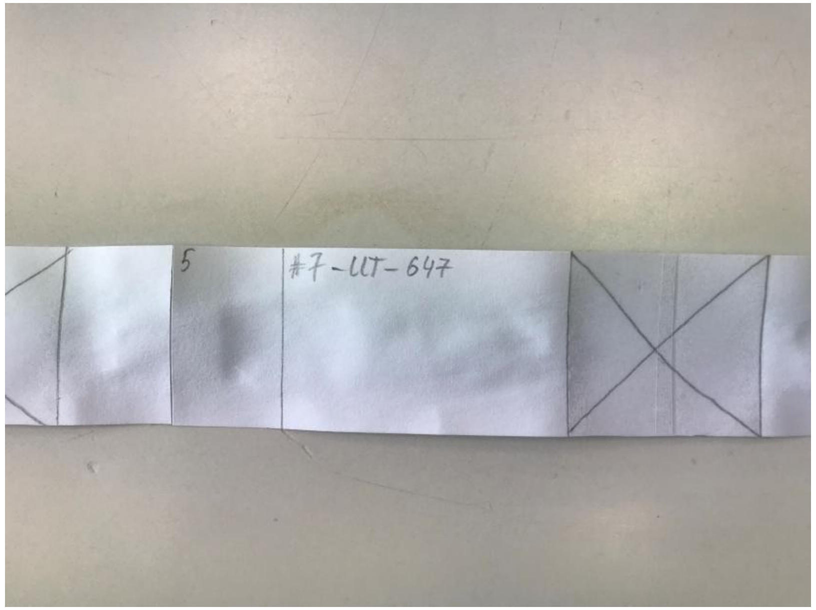
- water penetrates the paper to its full thickness, regardless of the type of paper;

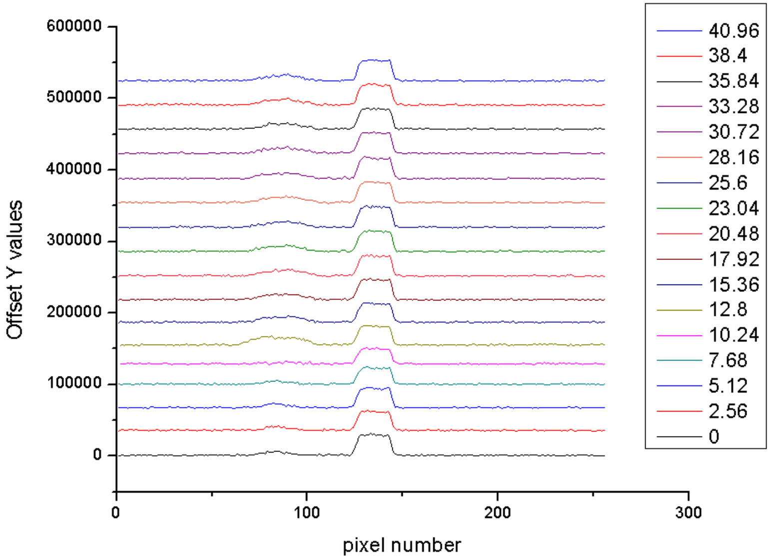
- water drying is very slow, compared to the drying of the ink seen in previous experiments.

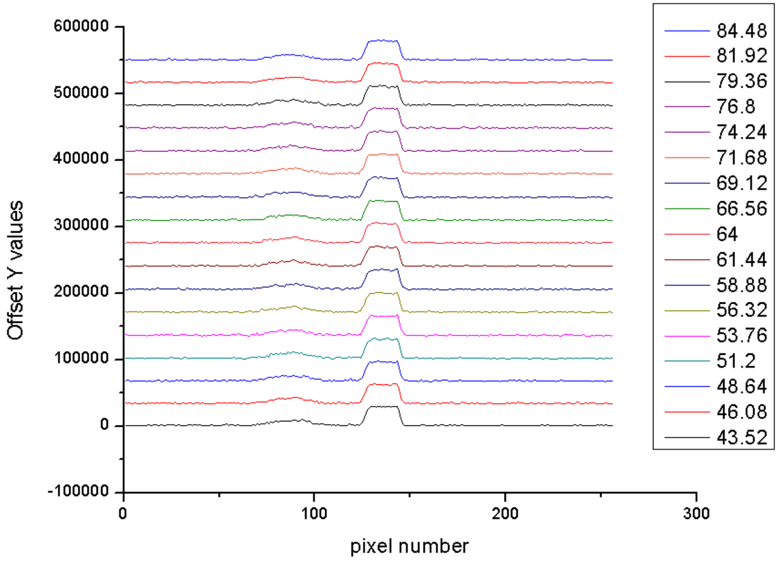
Only water impregnation

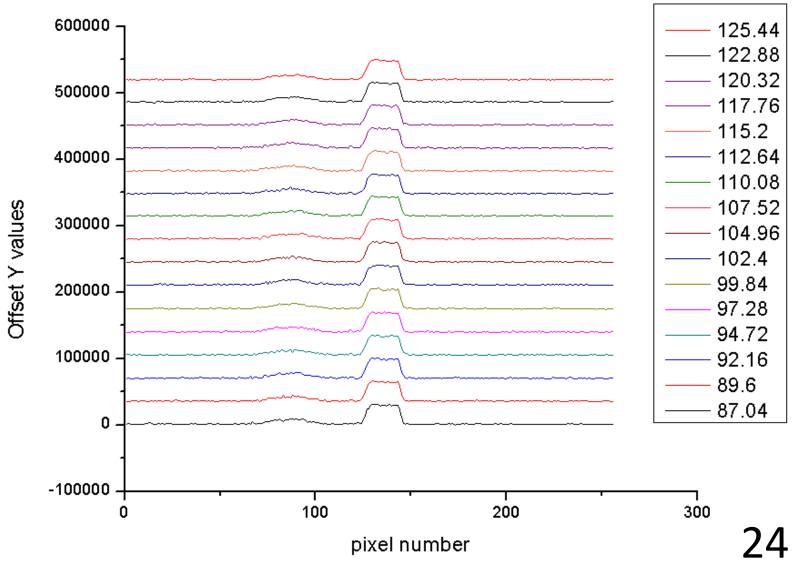
UT paper #7 - 647



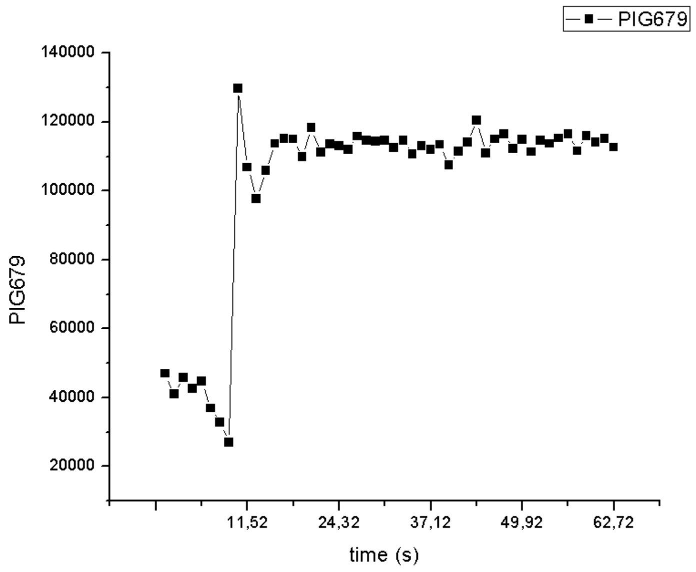


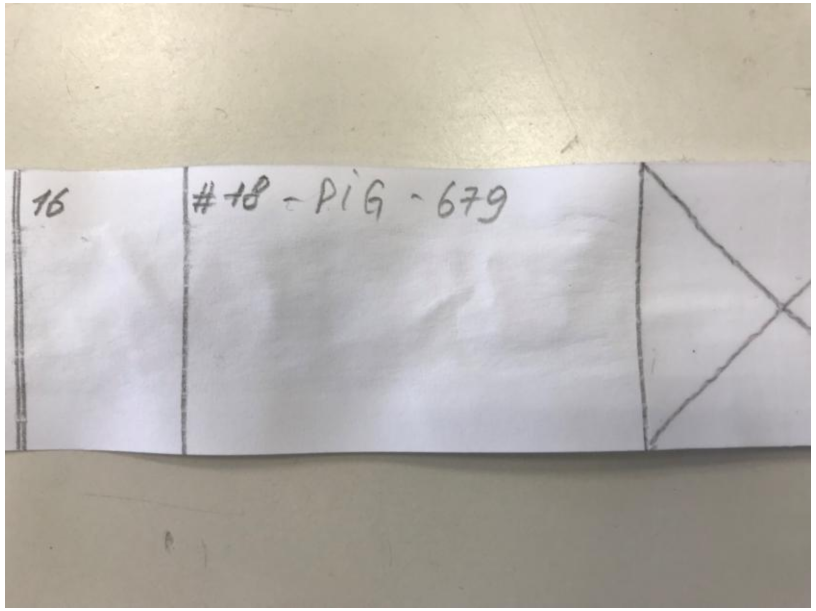


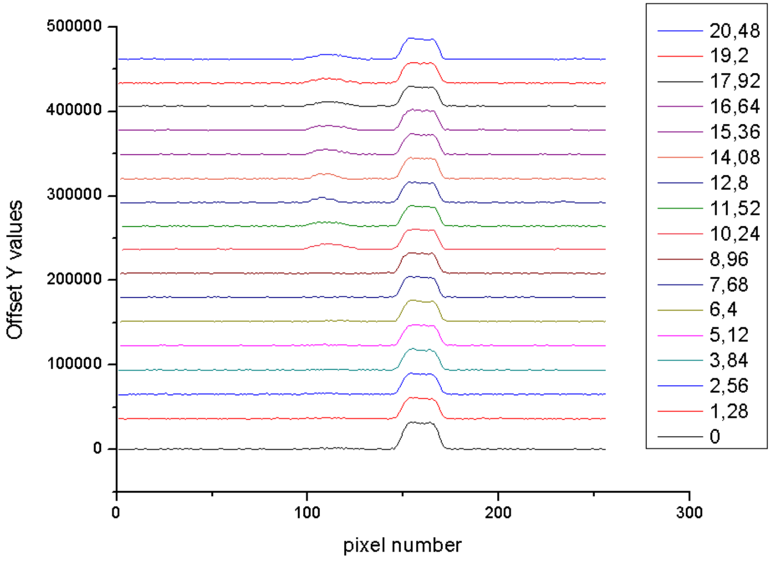


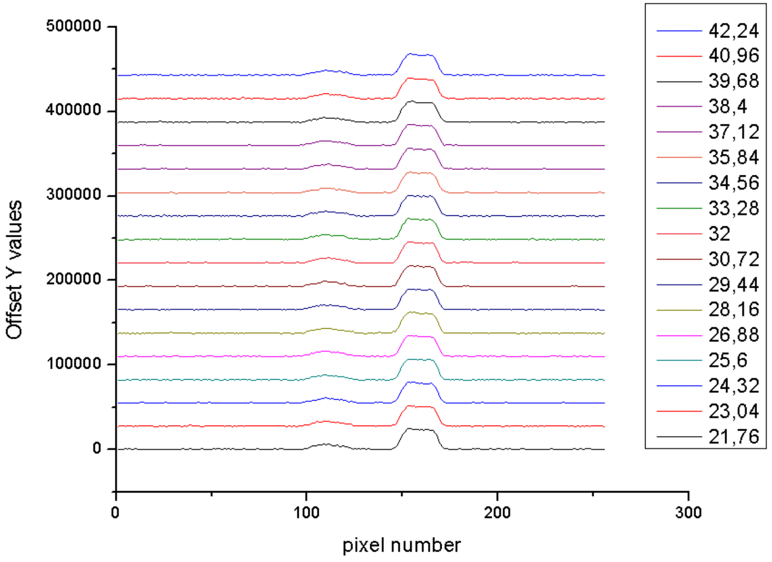


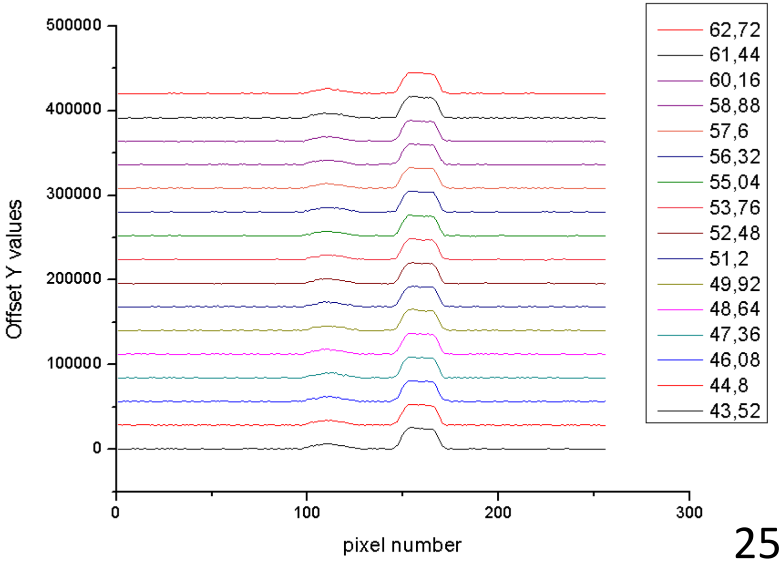
PIG paper #18 - 679



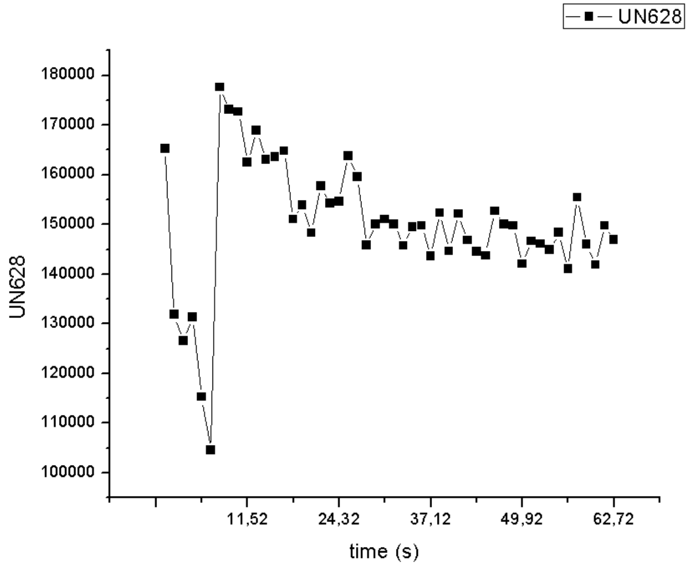


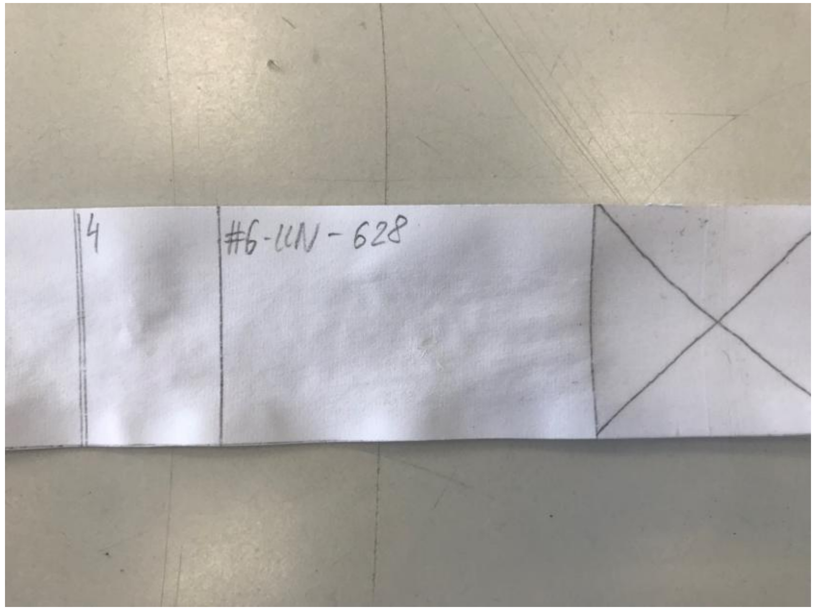


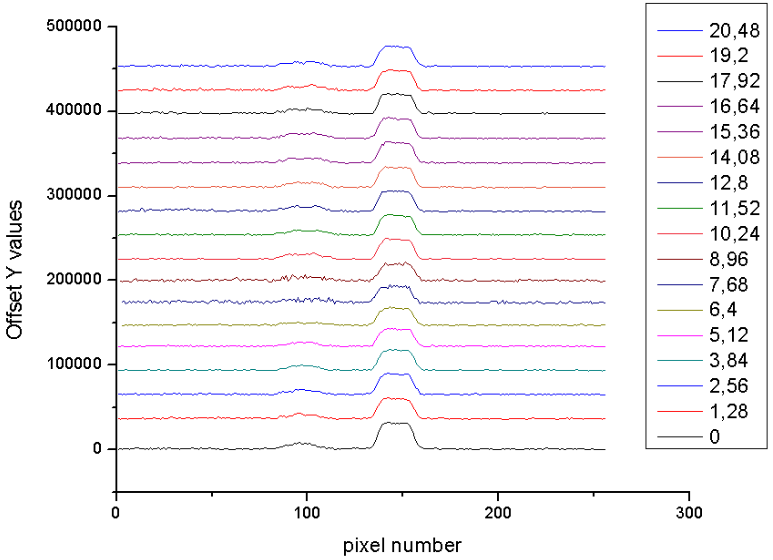


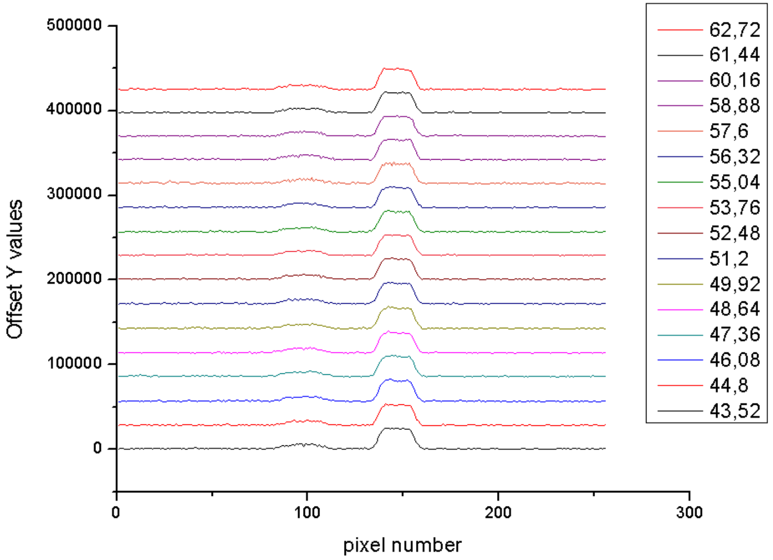


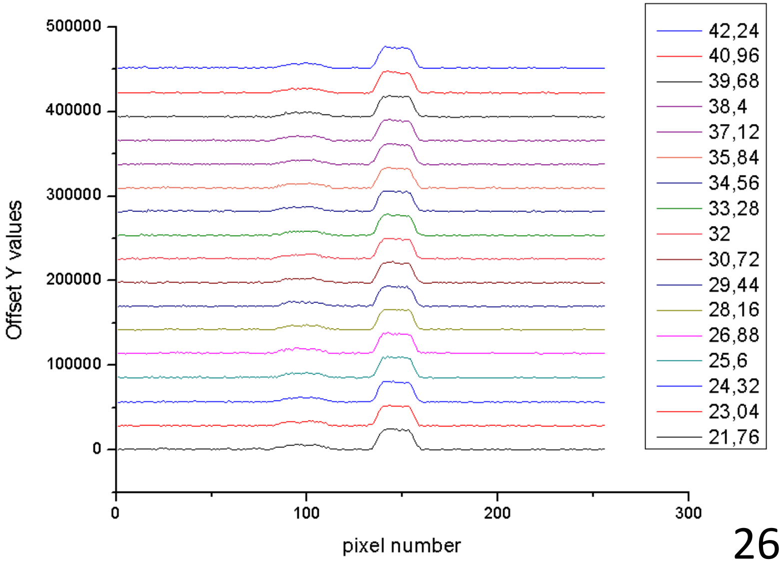
UN paper #6 – 628











Conclusion

- During these experiments were made several types of procedures, works, which most of them were successful.
- While the imaging method (1D profiles) is interesting for measuring the penetration thickness and drying rate, it does not allow (this was anticipated) to achieve a temporal resolution sufficient to see the penetration front. The transport of the liquid deposited on the surface is carried out over a time scale of a few hundred milliseconds. NMR, on the other hand, can be clearly distinguished from other methods by providing information on the distribution of different liquids in the paper during, for example, demixing phenomena.

Thanks for attention!