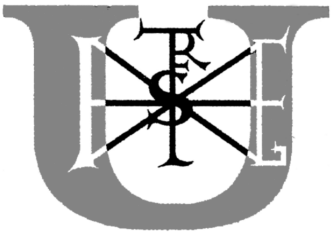


Szent István University

ELECTRORHEOLOGICAL FLUIDS IN FLOW MODE

Thesis of the doctoral (Ph.D) dissertation

László Földi

Gödöllő
2012

The doctor's school

designation: Mechanical Engineering Ph.D School

discipline: Agricultural Technical Science

head of school: **Dr. István Farkas**
professor, DSc
Szent István University,
Faculty of Mechanical Engineering
Gödöllő

Supervisor: **Dr. László Jánosi**
Professor, CSc
Szent István University,
Faculty of Mechanical Engineering
Institute for Mechanical Engineering Technology
Gödöllő

……. ……

Approved by head of school Approved by supervisors

CONTENTS

1. INTRODUCTION, GOALS

1.1. Actuality of theme

In mechatronical applications and researches the use of the so-called „intelligent" materials has become significant. In certain fields problems occured that couldn't be solved any more by using new materials which had been developed with material structure modifications.

A specific manifestation of the information flow can be observed in one of the wings of material science. The main motive of this aspiration is the approach of the operation and efficiency and also the environment-friendly features of biological materials, which are far more perfect than our technical means. The objective is to create materials which sense the changes of their environment then they react to these changes in a way that is beneficial for the user.

In the research of mechatronical system a claim has emerged for developing materials, which understand the information coming from the computer and modify their properties accordingly. The established connection between the computer and the material limits the material features that can be influenced by the computer. This transmission can only be ensured by effects whose speed of induction and cancellation can be measured – or even bigger – than that of the speed of control and the change-speed of the material feature. From the point of view of control engineering, the application of electric and magnetic field seems to be the most obvious.

The significant sensibility to electric and magnetic fields is a typical attribute of solid bodies. The transmission of these attributes to other material systems is only possible if we disperse the particles found in the colloid size-range of these materials into material systems showing other attributes (eg. into fluids or flexible polimers). This task can be solved with the help of colloid science which means the chemical basics of nanotechnology. Electric and magnetic sensibility can be attained with the so-called complex fluids. These contain particles of nano- and micrometer size in homogeneous distribution. The particles have special electric and magnetic attributes and suggest as if the fluid itself showed electric and magnetic attributes. The complex fluids consist of three main groups: the electro-rheological (ER), the magneto-rheological (MR) and the magnetic fluids. By switching on and off the control field the physical or mechanical state of the fluid can be changed.

1.2. Research tasks set

The purpose of the research is the revelation of the dynamic behavioral laws of an ER fluid – composed of basic materials which were selected on the basis of tests – in flow mode. During the experiment we need the elaboration of a measuring system and a test method by which – from the measured pressure drop and flow

rate – we can define dynamically the shear stress increase of the fluid which derives from the ER effect (apparent viscosity increase).

It was also my objective to define the mathematical models based on the measurement results, depicting the electric field-, flowrate- and additive material dependency of the pressure increase of the tested ER fluid, which derives from its shear stress change.

The experiment consists of the elaboration of the following fields:

- Creating the ER fluid using the various basic fluids and additive materials.
- The co-testing and evaluation of the basic fluids and the additive materials (ER fluids), with special regard to the sedimentation of the additive material and insulation strength.
- Working out a new measuring system and test method suitable to unfold the ER attributes, which **cannot be measured** with the test systems functioning on the principle of rotation, which systems are generally used in experiments.
- Definition of the dynamic behaviour of the selected ER fluid in flow mode.
- Based on measurement data, definition of the mathematical model depicting the electric field dependency of the pressure increase, which derives from the shear stress increase of the selected ER fluid. $\Delta p_{ER} = f(E)$
- Based on measurement data, definition of the mathematical model depicting the flowrate dependency of the pressure increase, which derives from the shear stress increase of the selected ER fluid. $\Delta p_{ER} = f(Q)$
- Based on measurement data, definition of the mathematical model depicting the additive material dependency of the pressure increase, which derives from the shear stress increase of the selected ER fluid. $\Delta p_{ER} = f(m)$
- Based on measurement data, definition of the mathematical model depicting the electric field and flowrate dependency of the pressure increase, which derives from shear stress increase of the ER fluid of given additive material concentration. $\Delta p_{ER} = f(E,Q)$

2. MATERIAL AND METHOD

2.1. The operation of the ER test system

The main objective of this experiment is the test of ER fluids and that of the ER phenomenon regarding hydraulic applications and applicability. Thus, the planned test equipment is a construction built in a hydraulic system, which is based on the principle that if the hydraulic fluid applied in the system has the features of an ER fluid, then using the ER phenomenon, the hydraulic parameters of the system can be modified. This can be carried out by building a special-layout flow cross-section into the hydraulic system (Figure 2.1.), which under the ER phenomenon – by increasing the shear stress of the fluid – shows an analogue behaviour with the throttle valve.

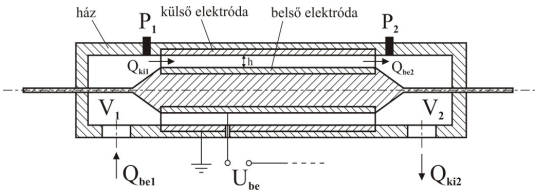


Figure 2.1. The „ER valve”

In the flow mode system composed by myself, the constant shear field is ensured by the constant flowrate flowing through the ER valve. This way the magnitude of the shear stress arising from the electric field in the fluid can be calculated from the pressure drop and the flowrate measured at the ER valve (τ_{ER}):

$$\Delta p_{12} = \frac{12 \cdot \eta \cdot L \cdot Q}{b \cdot h^3} + \frac{2 \cdot L \cdot \tau_{ER}}{h} \Rightarrow \tau_{ER}$$

In the formule L the length of the electrodes of the valve, η the dynamical viscosity of the ER fluid, b the circumference of the electode, h the gap size between the electrodes are known parameters, Q and Δp_{12} are the flowrate and pressure drop at the ER valve.

2.2. Blending tests of ER fluids

To produce the ER fluid I used particles and basic fluids of various materials. For creating a stable suspension application of a dispergent is needed. Its role is to hinder the sedimentation of the particles, which is a basic criteria of the applicability of ER fluids. Basic fluids: silicon oil, SN 150A (46) mineral oil. Solid constituent: starch, talcum, TiO_2, PTFE, soot. In table 2.1 the results of the blending tests are shown.

Table 2.1 Results of the blending tests

Basic fluid	Additive material	m_a [%]	Dispergent	m_d [%]	Sedimentation	insulation strength [kV/mm]	Zerofield viscosity [mPas]
SN 150A	Talcum	5	Komad 309A	1	Consolidated	$E_{átüt}$ > 10 kV/mm	-
SN 150A	Soot	5	Komad 309A	1	Consolidated	$E_{átüt}$ > 10 kV/mm	-
SN 150A	PTFE	5	Komad 309A	1	Consolidated	$E_{átüt}$ > 10 kV/mm	-
SN 150A	TiO_2	5	Komad 309A	2	Stable	$E_{átüt}$ > 10 kV/mm	84,2 mPas
SN 150A	TiO_2	10	Komad 309A	4	Stable	$E_{átüt}$ > 10 kV/mm	112,3 mPas
SN 150A	TiO_2	30	Komad 309A	6	Stable	$E_{átüt}$ > 10 kV/mm	176,8 mPas

2.3. Experiment plan

In the tests I switch the electric field step-response-like and so I measure the pressure drop at the valve. I examine the change of the measured pressure drop in time. The changed parameters are the flowrate flowing through the ER valve (Q), the electric field (E) – which can be computed from the voltage controlled by the high voltage amplifier and the distance between the electrodes (U_{ki}) - and the additive material concentration of the ER fluid (m).

Table 2.2. Test settings (flowrate)

Q_1 [liter/min]	Q_2 [liter/min]	Q_3 [liter/min]	Q_4 [liter/min]	Q_5 [liter/min]
0,42	0,65	0,85	1,05	1,3

Table 2.3. Test settings (electric field)

E_1 [kV/mm]	E_2 [kV/mm]	E_3 [kV/mm]	E_4 [kV/mm]	E_5 [kV/mm]	E_6 [kV/mm]
0	2	4	6	8	10

Table 2.4. Test settings (additive material concentration)

m_1 [m%]	m_2 [m%]	m_3 [m%]	m_4 [m%]
0	10	20	30

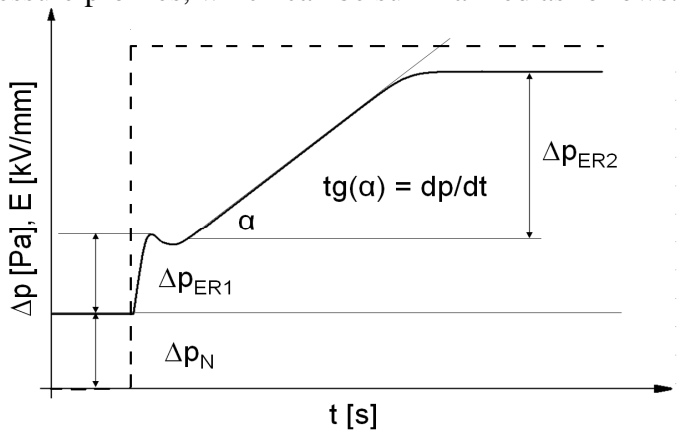
Thus, my experiment plan consists of 120 settings, I carried out 5 repetitions per each setting.

During the preliminary tests I observed some phenomena, which hadn't been mentioned in the literature (since these phenomena cannot be shown with test systems operating under the rotational principle). Such phenomena are the Δp_2 és dp/dt, whose exact explanation will be given in the Results chapter.

3. RESULTS

3.1. Analysing the process of pressure increase

In my test system (ER valve) flow mode prevails. Unlike the pressure profiles that we can read about in the literature, in the cases I examined I experienced different pressure profiles, which can be summarized as follows:



Δp_N	-	pressure increase deriving from the basic viscosity	[Pa]
Δp_{ER1}	-	primary pressure increase deriving from the ER effect	[Pa]
Δp_{ER2}	-	secondary pressure increase deriving from the ER effect	[Pa]
dp/dt	-	intensity of the secondary pressure increase	[Pa/s]
E	-	electric field	[kV/mm]

Figure 3.1. Sections of the pressure profile in flow mode

The pressure profile consists of the following sections.. The pressure of the section that precedes the switching on of the electric field is given from the viscosity of the ER fluid (Δp_N).

After switching on the electric field a rapid pressure increase can be experienced whose response time is a value of 20-40 ms. Then the pressure drop diminishes, it reaches a minimum value, then it increases again. The average value of the minimum and maximum of this section – after deducting the pressure increase deriving from the basic viscosity (Δp_N) – is designated as the **primary pressure increase (Δp_{ER1})** by me.

The secondary pressure increase goes on till a maximum value. The intensity of this secondary pressure increase is smaller with some orders of magnitude than that of the primary pressure increase. Its profile can be approached by a linear trend, I designate the field of this section as **intensity of the secondary pressure increase** (**dp/dt**).

After deducting the pressure increase deriving from the basic viscosity (Δp_N) and the primary pressure increase (Δp_{ER1}) - I name the maximum value attained by the pressure increase as **secondary pressure increase** (Δp_{ER2}).

3.2. Examination of the electric field and flowrate dependency of the primary pressure increase

Having examined the dependency of the primary pressure increase from the various variables (E, Q) I got an image about the mathematical approaching relations of the pressure increasing process. From the results of the measurements it was apparent that the electric field dependency of the primary pressure increase can be approached by a power function well. However, we can also see as the result of the examinations that the primary pressure increase – though to a very small extent, but – changes in the function of the flowrate. The change can be approached by a linear trend. Hence, I selected the following function for the electric field- and flowrate dependency of the primary pressure increase:

$$\Delta p_{ER1} = (a \cdot Q + b) \cdot E^{c \cdot Q + d}$$

Where:
- Q flowrate [*L/min*]
- E electric field [*kV/mm*]
- a $\left[\frac{Pa \cdot mm \cdot min}{kV \cdot L}\right]$, b $\left[\frac{Pa \cdot mm}{kV}\right]$, c $\left[\frac{min}{L}\right]$, and d [-] parameters

The chart shows the values of the primary pressure increase (Δp_{ER1}) at the various settings. In the chart we can also see the known function, whose parameters (a, b, c, d) were determined by the least squares method.

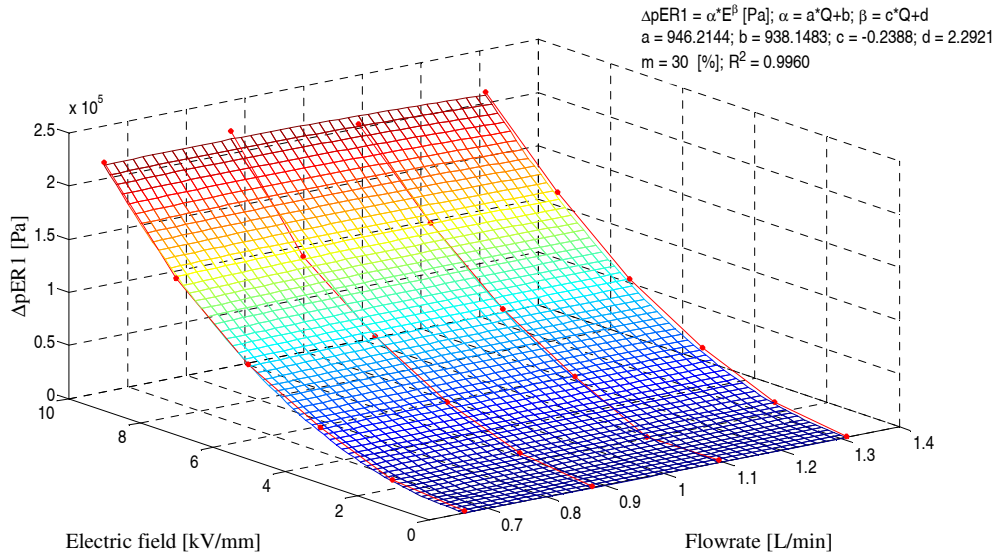


Figure 3.2. Primary pressure increase in the function of the electric field and flowrate (m = 30% additive material concentration TiO_2/SN150A blend)

The approaching function, by which the value of the primary pressure increase in the function of the electric field and the flowrate (at p = 99% probability level), in the case of m = 30% additive material concentration blend, in Q = 0,66 – 1,31 L/min and E = 0 – 10 kV/mm validity scope:

$$\Delta p_{ER1} = (946{,}2144 \cdot Q + 938{,}1483) \cdot E^{-0{,}2388 \cdot Q + 2{,}2921} \pm 16010 \quad [Pa]$$

With the defined relation the value of the primary pressure increase can be determined knowing the flowrate and the electric field in flow mode.

3.3. Examination of the additive material dependency of the the primary pressure increase

The diagram shows the mean values of the primary pressure increase (Δp_{ER1}) at the various test settings (additive material concentration m = 0, 10, 20, 30 %), the deviations ($\pm 2\sigma$) at the various test settings are also shown.

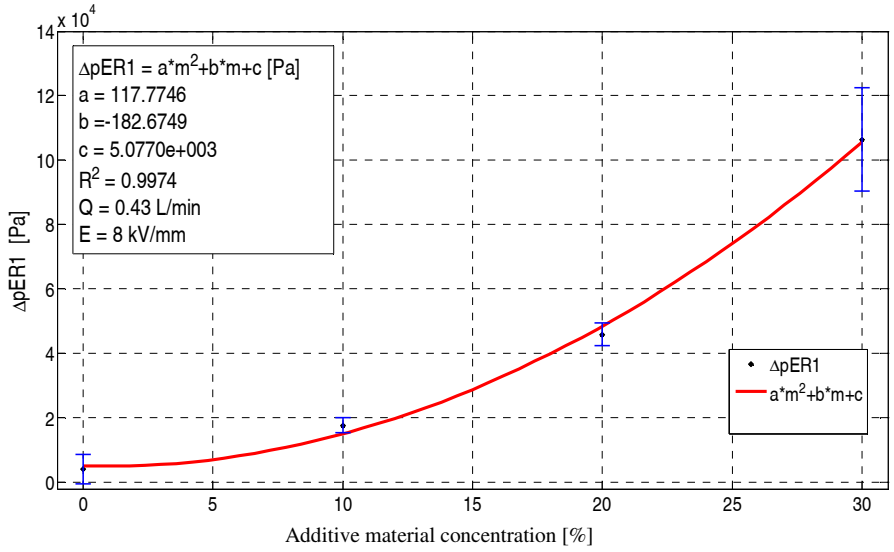


Figure 3.3.
Additive material concentration dependency of the primary pressure increase at a flowrate of 0,43 L/min

I approach the relation between the additive material concentration and the primary pressure increase with the function of:

$$\Delta p_{ER1} = a \cdot m^2 + b \cdot m + c$$

where m is the additive material concentration [%] and a [Pa], b [Pa] and c [Pa] are parameters.

The solid line illustrates the above mentioned function, whose parameters were determined by the least squares method.

3.4. Electric field and flowrate dependency of the secondary pressure increase

Having examined the dependency of the secondary pressure increase from the various variables (E, Q) I got an image about the mathematical approaching relations of the pressure increasing process. From the results of the measurements it was apparent that the electric field dependency of the secondary pressure increase can be approached by autocatalytic functions well. As a result of the tests we could also observe that the secondary pressure increase changes autocatalytically too, in the function of the flowrate. In view of this, I chose the following function for approaching the electric field and flowrate dependency of the secondary pressure increase:

$$\Delta p_{ER2} = (a \cdot E + b) \cdot \left(\frac{1}{1 + e^{c + d \cdot Q}} \right) + (\alpha \cdot Q + \beta) \cdot \left(\frac{1}{1 + e^{\gamma + \delta \cdot E}} \right)$$

Where:

- Q Flowrate [*L/min*]
- E Electric field [*kV/mm*]
- a [*mm/kV*], b [*Pa*], c [-], d [*min/L*], α [*min/L*], β [*Pa*], γ [-], and δ [*mm/kV*] parameters.

I fitted this function on the mean values of the secondary pressure increase measured at several experimental settings. I defined the parameters by the least squares method.

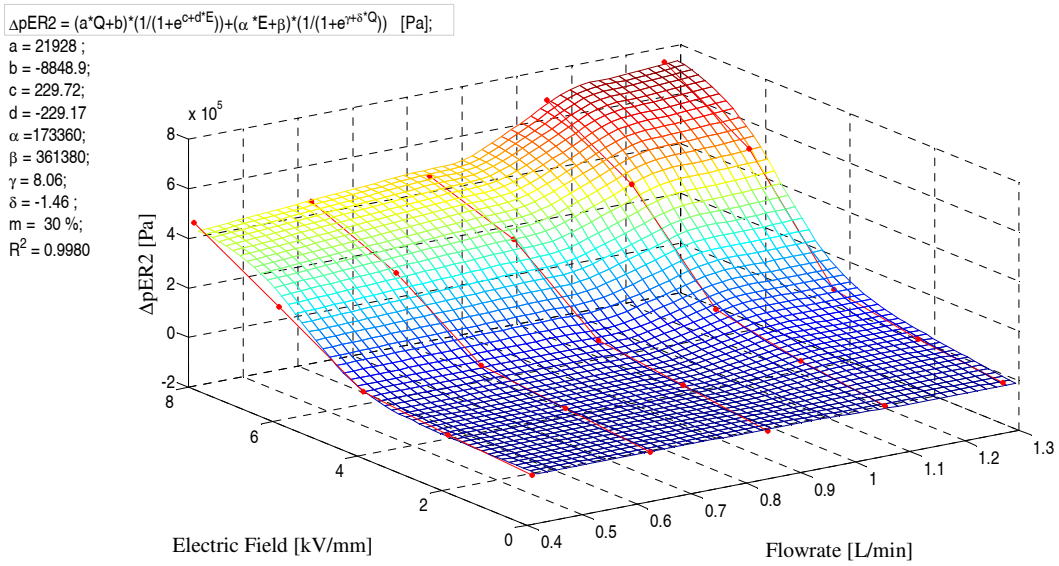


Figure 3.4. Secondary pressure increase in the function of the electric field and the flowrate (m = 30 % additive material concentration TiO_2/SN150A blend)

The figure shows the mean values of the secondary pressure increase ($\Delta p_{ER\,2}$) at several experimental settings. The figure also shows the function mentioned above.

The approaching function, by which the value of the secondary pressure increase in the function of the electric field and the flowrate (at p = 99% probability level), in the case of m = 30% additive material concentration TiO_2/SN150A blend, in Q = 0,42 – 1,31 L/min and E = 0 – 8 kV/mm validity scope is:

$$\Delta p_{ER2} = (21928 \cdot Q - 8848{,}9) \cdot \left(\frac{1}{1 + e^{229{,}72 - 229{,}17 \cdot E}} \right) + (173360 \cdot E + 361380) \cdot \left(\frac{1}{1 + e^{8{,}06 - 1{,}46 \cdot Q}} \right) \pm 91117 \ [Pa]$$

With the defined relation the value of the secondary pressure increase can be determined knowing the flowrate and the electric field in flow mode.

3.5. Examination of the additive material concentration dependency of the secondary pressure increase

I approach the relation between the additive material concentration and the secondary pressure increase with the

$$\Delta p_{ER2} = a \cdot m^2 + b \cdot m + c$$

function, where m [%] is the attitive material concentration, a [Pa], b [Pa] and c [Pa] parameters.

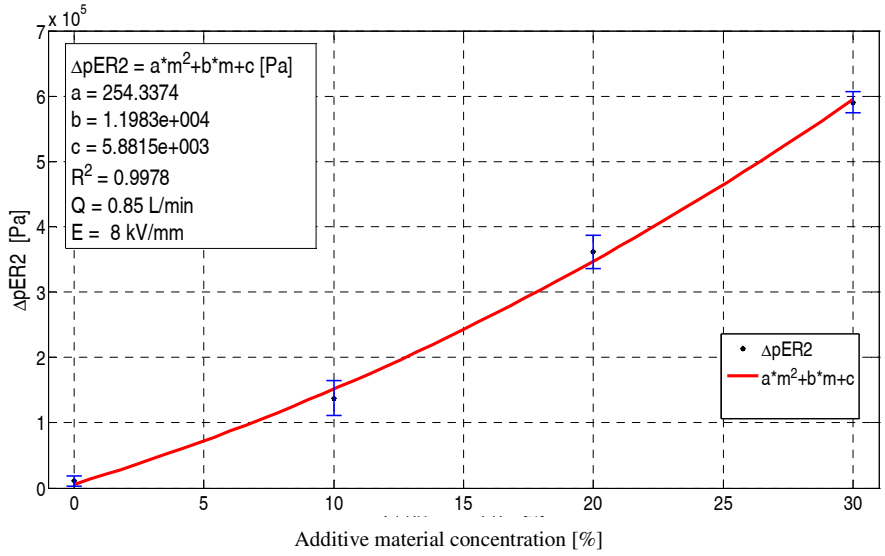


Figure 3.5. ábra
Additive material concentration dependency of the secondary pressure increase at a flowrate of 0,85 L/min and an electric field of 8 kV/mm

The diagram shows the mean values of the secondary pressure increase (Δp_{ER2}) at the various test settings (additive material concentration m = 0, 10, 20, 30 %), the deviations ($\pm 2\sigma$) at the various test settings are also shown.

The solid line illustrates the known function.

The correlational coefficient of the function fitted on the mean values of the secondary pressure increase is bigger than 0.95 at every test.
The secondary pressure increase can be approached by the following function:

$$\Delta p_{ER2} = a \cdot m^2 + b \cdot m + c$$

3.6. Examination of electric field and flowrate dependency of the intensity of the secondary pressure increase

Having examined the dependency of the secondary pressure increase intensity from the various variables (E, Q) I got an image about the mathematical approaching relations of the pressure increasing process. From the results of the measurements it was apparent that the electric field dependency of the secondary pressure increase intensity can be approached by a power function well. We can also see as the result of the examinations that the secondary pressure increase intensity changes in the function of the flowrate. In view of this, I chose the following function for the electric field- and flowrate dependency of the intensity of the secondary pressure increase:

$$\frac{dp}{dt} = (a \cdot Q + b) \cdot E^{c \cdot Q + d}$$

where:
- Q flowrate [*L/min*]
- E electric field [*kV/mm*]
- a $\left[\frac{Pa \cdot min \cdot mm}{L \cdot kV \cdot s} \right]$, b $\left[\frac{Pa \cdot mm}{kV \cdot s} \right]$, c $\left[\frac{min}{L} \right]$, and d [-] parameters

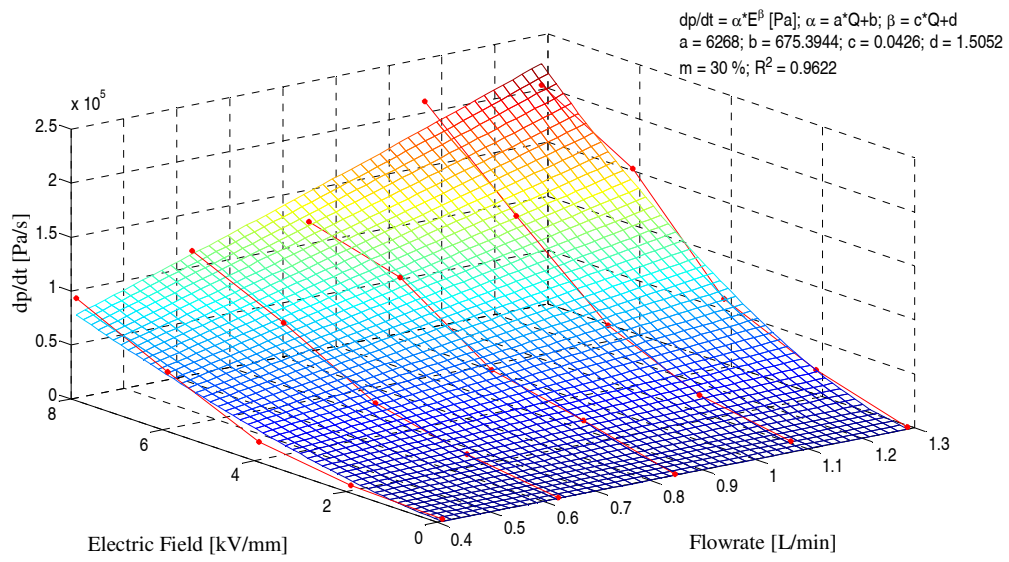


Figure 3.6. Secondary pressure increase intensity in the function of the electric field and the flowrate (m = 30 % additive material concentration TiO_2/SN150A blend)

The chart shows the mean values of the secondary pressure increase intensity at the various test settings.

The figure also shows the function mentioned above, whose parameters (a, b, c, d) were defined by the least square method.

The approaching function, by which the value of the secondary pressure increase intensity in the function of the electric field and the flowrate (at p = 99% probability level), in the case of m = 30% additive material concentration TiO_2/SN150A blend, in Q = 0,41 – 1,31 L/min and E = 0 – 8 kV/mm validity scope is:

$$\frac{dp}{dt} = (6268{,}0 \cdot Q + 675{,}3944) \cdot E^{0{,}0426 \cdot Q + 1{,}5052} \pm 43020 \ \ [Pa/s]$$

With the defined relation the value of the secondary pressure increase intensity can be determined knowing the flowrate and the electric field in flow mode.

3.7. Examination of the additive material concentration dependency of the secondary pressure increase intensity

I approach the relation between the additive material concentration and the secondary pressure increase intensity with the

$$\frac{dp}{dt} = a \cdot m^2 + b \cdot m + c$$

function, where m [%] is the attitive material concentration, a [Pa/s], b [Pa/s] and c [Pa/s] parameters.

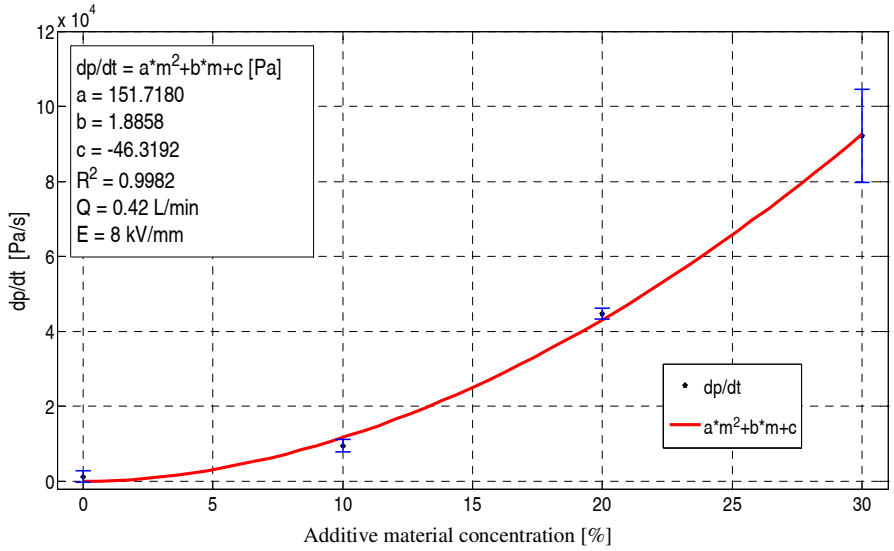


Figure 3.7. esetén Additive material concentration dependency of the secondary pressure increase intensity at a flowrate of 0,42 L/min and an electric field of 8 kV/mm

The diagram shows the mean values of the secondary pressure increase intensity at the various test settings (additive material concentration m = 0, 10, 20, 30 %), the deviations ($\pm 2\sigma$) at the various test settings are also shown. The solid line illustrates the known function.

The correlational coefficient of the function fitted on the mean values of the secondary pressure increase intensity is bigger than 0.95 at every test. The intensity of the secondary pressure increase can be approached by the following function:

$$\frac{dp}{dt} = a \cdot m^2 + b \cdot m + c$$

4. NEW SCIENTIFIC RESULTS

The new scientific results are valid under the following conditions: the tests were made with SN 150 A mineral oil and with 5 μm particle size TiO_2 blend. For making a stable blend I applied a Komad 309A type dispergent. The blending ratio ranges from 0 to 30 mass percent, and the magnitude of the applied electric field ranges from 0 to 8 kV/mm. I varied the flowrate between 0,66-1,3 L/min. The test temperature of the ER fluid is 25°C. The nomenclature in the theses: Δp_{ER1} - primary pressure increase [Pa]; Δp_{ER2} - secondary pressure increase [Pa]; dp/dt – intensity of the secondary pressure increase [Pa/s]; E – electric field [kV/mm]; Q – flowrate [L/min]; m – additive material concentration [%] a, b, c, d, α, β, γ, δ parameters.

1. thesis
I established that in flow mode, as the effect of a step response-type electric field, the pressure increase given from the shear stress-change consists of two sections: a rapid primary pressure increase right after the switching on of the electric field, and a slower secondary (of longer response time) section. I aslo established that the intensity of the primary pressure increase is bigger by an order of magnitude than that of the secondary pressure increase. To justify this, I worked out a measuring system and an examination procedure.

2. thesis
I proved that the magnitude of the primary pressure increase depends on the applied electric field, the additive material concentration and on the flowrate.

2/a. I proved that extent of the primary pressure increase following the turning on of the electric field – applying a given additive material concentration – shows a power-function correlation with the applied electric field. This can be depicted by the following equation:

$$\Delta p_{ER1} = \alpha \cdot E^{\beta}$$

(The parameters of the equation have to be defined in function of the flowrate and the additive material concentration.)

2/b. I proved that the extent of the primary pressure increase after turning on the electric field – applying a given electric field – shows a

correlation with the additive material concentration of the fluid that can be approached by a polynom of the second degree.

$$\Delta p_{ER1} = a \cdot m^2 + b \cdot m + c$$

(The parameters of the equation have to be defined in function of the applied electric field and the flowrate.)

3. thesis

I proved that the extent of the secondary pressure increase – which isn't mentioned in the literature – depends on the electric field, the additive material concentration and on the flowrate.

3/a. I proved that the extent of the secondary pressure increase succeeding the electric field turning on – in case of a given additive material concentration – shows correlation with the electric field which can be approached by an autocatalytic function. The next equation depicts this correlation:

$$\Delta p_{ER2} = \alpha \cdot \left(\frac{1}{1 + e^{\beta + \gamma \cdot E}} \right)$$

(The parameters of the equation have to be defined in function of the flowrate and the additive material concentration.)

3/b. I proved that the extent of the secondary pressure increase after turning on the electric field – applying a given electric field – shows a correlation with the additive material concentration of the fluid that can be approached by a polynom of the second degree. The next equation depicts this correlation:

$$\Delta p_{ER2} = a \cdot m^2 + b \cdot m + c$$

(The parameters of the equation have to be defined in function of the applied electric field and the flowrate.)

4. thesis

I justified by my measurements that the intensity of the secondary pressure increase ***(dp/dt)*** depends on the applied electric field, the additive material concentration and on the flowrate.

4/a. I proved that intensity of the secondary pressure increase following the turning on of the electric field – applying a given additive material concentration – shows a power-function correlation with the applied electric field. This can be depicted by the following equation:

$$\frac{dp}{dt} = \alpha \cdot E^{\beta}$$

(The parameters of the equation have to be defined in function of the flowrate and the additive material concentration.)

4/b. I proved that the intensity of the secondary pressure increase ***(dp/dt)*** after turning on the electric field – applying a given electric field – shows a correlation with the additive material concentration of the fluid that can be approached by a polynom of the second degree. The next equation depicts this correlation:

$$\frac{dp}{dt} = a \cdot m^2 + b \cdot m + c$$

(The parameters of the equation have to be defined in function of the applied electric field and the flowrate.)

5. thesis

On the basis of the measurement data I determined the flowrate and electric field dependency of the primary and secondary pressure increase and that of the intensity of the secondary pressure increase concerning a given additive material concentration ER fluid.

5/a. The connection between the **primary pressure increase** and the flowrate and the electric field $\Delta p_{ER1} = f(E,Q)$ – in the case of a given additive material concentration ER fluid – can be approached by the following function:

$$\Delta p_{ER1} = (a \cdot Q + b) \cdot E^{c \cdot Q + d}$$

(the parameters of the equation should be determined in the function of the applied additive material concentration)

5/b. The relationship between the **secondary pressure increase** and the electric field and the flowrate $\Delta p_{ER2} = f(E,Q)$ – in the case of a given

additive material concentration ER fluid – can be approached by the following function:

$$\Delta p_{ER2} = (a \cdot E + b) \cdot \left(\frac{1}{1 + e^{c+d \cdot Q}} \right) + (\alpha \cdot Q + \beta) \cdot \left(\frac{1}{1 + e^{\gamma + \delta \cdot E}} \right)$$

(the parameters of the equation should be determined in the function of the applied additive material concentration)

5/c. The relationship between the **intensity of the secondary pressure increase** and the electric field and the flowrate $\frac{\mathrm{dp}}{\mathrm{dt}} = \mathrm{f}(\mathrm{E},\mathrm{Q})$ – in the case of a given additive material concentration ER fluid – can be approached by the following function:

$$\frac{dp}{dt} = (a \cdot Q + b) \cdot E^{c \cdot Q + d}$$

(the parameters of the equation should be determined in the function of the applied additive material concentration)

5. CONCLUSIONS, SUGGESTIONS

In the course of my work, I obtained numerous experience in connection with the behaviour of the examined material which have theoretical and practical relations.

For the revelation of the laws and fundamental relationships I used a basic oil and additive material. The tightness of the relationships revealed in this paper, the rates of the corelations between the dependent and the independent variables suggest that we have such laws before us whose tendencies are identical, their rates, however, can be different and they depend on the individual features of the applied materials. On the basis of this reasoning we can draw the conclusion that the elaborated procedure can be applied to define the properties of any other material match. The general formes of the established equations are identical, their parameter, however, are different. The parameters concerning further material combinations are to define by repeated measurements later. The unfolded relationships, therefore irrespectively of the individual material match, will be valid in a wider range.

During the measurements I observed that the time interval between the measurements exerted an effect to the tested phenomenon. Presumably, the distribution of the additive material in the fluid, and its local concentration influence the results of the tests. On the grounds of this experience, I compiled my measurements in a way that each and every repetition could happen under the same initial conditions. In order to solve this, I „homogenised" the tested material by blending without using the electric field before each and every measurement setting, that is, I kept on blending to attain the initial viscosity of the fluid. In lab-circumstances this method can ensure the identical conditions of the measurements, but in reality we must be aware of these influences. For this reason, I propose the elaboration and fulfilment of new examinations by which the behaviour of the fluid can be defined under changing initial conditions too. This means that we must know the additive material concentration at every cross-section of the valve while the ER influence is on.

During the measurements I also observed that the flowrate has various effects on the secondary pressure increase. When I enhanced the flowrate, the intensity of the secondary pressure increase became more and more powerful. I found it an interesting phenomenon that the rate of the intensity increase also varied in the function of the flowrate. I evaded this effect by carrying out all measurement settings at the same flowrate. Hence, I propose the examination of the flowrate effect on the secondary pressure increase too in the future.

I did my tests under constant fluid temperature. It is an understood thing that the viscosity of the fluid is significantly influenced by its temperature, but it is unknown how the fluid temperature influences the ER phenomenon at the material combination applied in this research. As a further research task, I find it inevitable to reveal it.

A part of the filtering problems, which often occure in technological fields, can be correlated with the quantity and quality of the disperged foreign materials in the material to filter. Considering that the concentration of the polarisable particles in the fluid can be directed due to the ER effect, this effect enables the method to use it as a filter. This technics makes the application possible in industrial environments.

6. SUMMARY

ELECTRORHEOLOGICAL FLUIDS IN FLOW MODE

In the course of my work as the first step I reviewed the domestic and international vocational literature. After processing the literature I have established that the methods of the examinations of the ER fluids – from the respect of fluid mechanics - can be divided into two main groups: the one which is based on flow mode and the one based on share mode. The majority of the researchers carry on their examination of ER fluids with rotational electro-viscosimeters, thus a significant part of the material tests apply the share method, however, in hydraulic systems it is the flow mode that evolves. Seeing that I mainly devote the application areas of the ER valve to circles fulfilling hydraulic energy transport, I analyze flow mode relations which evolve in such circumstances. The literature of the examination methods based on this principle is, however, rather poorish.

In view of this I carried on my work elaborating an examination method resting on the flow mode, by the result of which I worked out a so called test concept based on ER valves.

I developed the test method based on the ER valve and I also built up the test equipment. Within this, I complied the hydraulic and electronic systems of the test equipment. I created its measure data collecting and measure controlling algorithms.

On the basis of mixing experiments I generated an ER fluid (SN 150A + TiO_2) and I did the test of the base liquid considering the stress and zero-field viscosity at 0, 10, 20, 30 mass percent additive material concentration as well.

In the course of my experiments I defined the typical press process of the ER fluid generated by myself under step response-shape electric field in flow mode systems. As a result of this I defined the primary and secondary pressure increase and its intensity.

I defined the relation between the primary pressure increase and the electric field, flowrate and additive material concentration. Also, I defined the secondary pressure increase and its electric field, flowrate and additive material concentration dependence.

On the grounds of my examinations I formulated my new scientific results, in addition I made proposals for the practical applications of the results attained and for fulfilling further research objects.

7. PUBLICATIONS IN CONNECTION WITH THE THEME OF DOCTORAL DISSERTATION

Articles in foreign language

Földi L., Sárközi E., Jánosi L.: Mathematical Analysis of Electro-Rheological Flow Control Valve R & D Mechanical Engineering Letters, 2008. Vol. 1., Hungary, pp. 107-112. HU ISSN 2060-3789

Földi L., Jánosi L.: Design of electro-rheological flow control valve. R & D Mechanical Engineering Letters, 2009.Vol. 2., Hungary, pp. 161-165. HU ISSN 2060-3789

Földi L., Jánosi L.: Short response time fluid flow control by new development ER valve. R & D Mechanical Engineering Letters, 2009.Vol 3., Hungary, pp. 102-110. HU ISSN 2060-3789

L. Földi, Z. Béres, E. Sárközi, L. Jánosi: Novel cylinder positioning system with solenoid valves. R & D Mechanical Engineering Letters, 2010.Vol 4., Hungary, pp. 151-165. HU ISSN 2060-3789

Földi L., Jánosi L.: Analysis of electro-rheological fluid in hydraulic system. Sustainable Construction & Design, 2010. Vol. 1. pp. 121-126. ISBN: 978-9-49072-600-3, ISSN: 2032-7471

Földi L., Jánosi L.: Test of the electro-rheological attributions of silicon oil without additives under flow mode. R & D Mechanical Engineering Letters, 2011.Vol 5., Hungary, pp. 121-127. HU ISSN 2060-3789, CD-ROM ISSN 2060-3797

Foldi L., Beres Z., Sarkozi E.: Novel cylinder positioning system realised by using solenoid valves. Sustainable Construction & Design, 2011. Vol. 2. Issue 1. pp. 142-151. ISSN 2032-7471

Articles in Hungarian language

Dr. Szabó I**. - Földi L. -** Madarász I**.**: Egy különleges mérnöki feladat: A "PHILIPS" hidromechanikus számítógép rekonstrukciós újratervezése. Gép, LIX. Évfolyam 2008/3 22-24. o. ISSN 0016-8572

Proceedings in foreign language

Földi L., Jánosi L.: Development of measuring system for testing electro-rheological effect. International Multidisciplinary Conference, 9th Edition, 19-21 May, 2011, Baia Mare – Nyiregyhaza, Romania – Hungary, pp. 103-108. ISBN 978-615-5097-18-8

Jánosi L, **Földi L.:** Electrorheologial properties of TiO_2/mineral oil suspensions under flow mode. 1st Regional Conference - Mechatronics in Practice and Education (MECH-CONF 2011) December 08 – 10, 2011 Subotica, Serbia. pp. 153-158. ISBN 978-86-85409-67-7

Proceedings in Hungarian language

Jánosi L, Sárközi E, **Földi L**, Józsa N. Kopásvizsgálatok növényi olajjal. XI. Nemzetközi Pneumatika-Hidraulika Konferencia. Miskolc, Magyarország, 2004.09.21-2004.09.23. Miskolc: 155-161. o.

Jánosi L, Valasek I, **Földi L**. Elektro-reológiai folyadékok hidraulikus alkalmazásai. Nemzetközi Mechatronika Szimpózium, BMF, Bánki Donát Gépészmérnöki Főiskolai Kar. Budapest, Magyarország, 2005.11.04. Budapest: 133-139. o. (ISBN:978-963-7154-59-1)

Jánosi L, **Földi L,** Horváth I. Gyulladási késedelem vizsgálatok növényi eredetű hajtóanyagokkal. MTA Agrár Műszaki Bizottság XXXI. Kutatási és Fejlesztési Tanácskozás. Gödöllő, Magyarország, 2007.01.23 Gödöllő: 133-139. o.

Földi L, Jánosi L. Elektroreológiai folyadékkal működő áramlásszabályozó szelep működésének vizsgálata szimulációs kísérleteken keresztül. Magyar Tudományos Akadémia Agrártudományok Osztálya Agrárműszaki Bizottság Kutatási és Fejlesztési Tanácskozás, Nr. 32. Gödöllő: FVM Mezőgazdasági Gépesítési Intézet - Szent István Egyetem Gépészmérnöki Kar, 2008. 303-309. o. (ISBN:978-963-611-449-7)

Földi L, Jánosi L. Hydraulic cylinder positioning by electro-rheological valve. Nemzetközi Mechatronika Szimpózium, Óbudai Egyetem, Bánki Donát Gépész és Biztonságtechnikai Mérnöki Kar, Budapest, 2009. november 10. Budapest, Magyarország, 2009.11.09 Budapest: Bánki Donát Műszaki Főiskola, 40-46. o.(ISBN:978-963-7154-59-1)