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# *Contamination control of Hydraulic Systems in Industry 4.0*

## *Authors*

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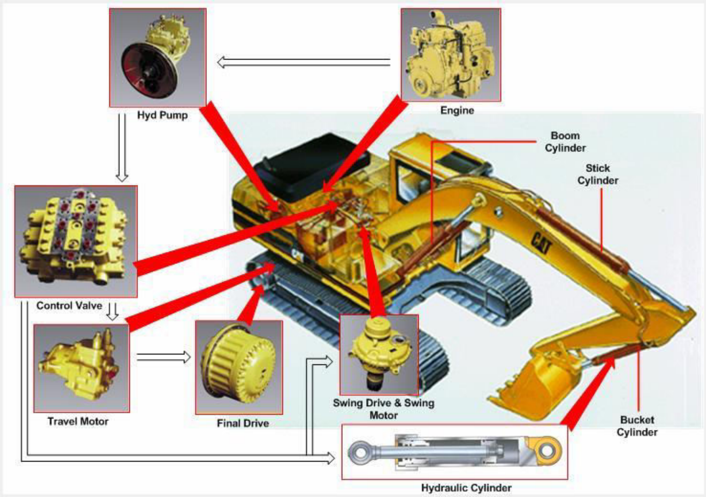
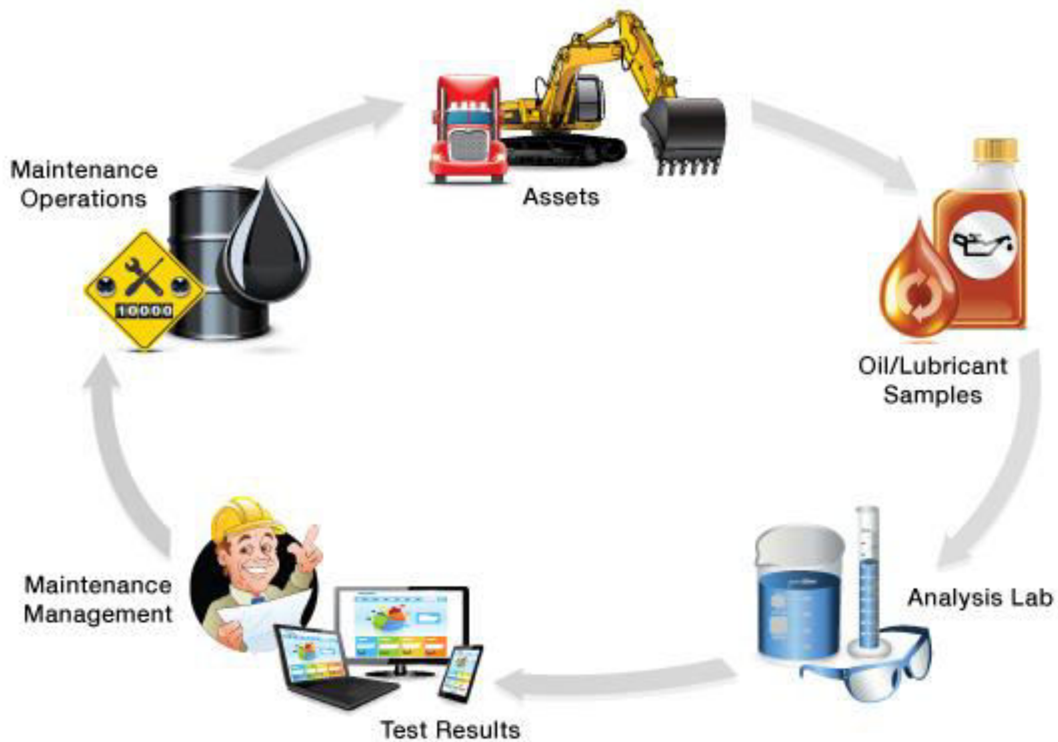
# Introduction

Modern hydraulic systems experience a constant increase in power demand, energy efficiency and higher reliability of components. Factors influencing the system performance are system design, regulation, quality of components and hydraulic fluid. Hydraulic fluid has to be considered as the most important component of a hydraulic system.



# Introduction

Influence of cleanliness of the oil is very important. Contamination of hydraulic control system has long been recognized as one of the major causes of components wear due to oil degradation. Considering the fact that oil reflects the state of the system the same way blood analysis reflects the condition of a human, monitoring an oil plays a vital role in maintenance decision making while ensuring the quality performance of the system.



# Introduction

Examples of damage from contaminants are: loss of lubrication and accelerated wear, blockage of flowing paths, formation of rust or other oxidation, depletion of additives, formation of acids and other chemicals which have negative influence, oil degradation.

# Motivation for the research

Hannover Messe 2011, one of the largest technology fairs, has been a creator of state-of-the-art term "Industrie 4.0".

Although the ideology of Industry 4.0 implies data exchanges, robots, big data, cloud, IoT, smart technologies and has been priority for many companies, centers and universities, generally accepted understanding of the term is still not explicitly defined.

Even so, paradoxically, technological development of Industry 4.0 has been widely accepted and followed by maintenance 4.0 as an integral part.

*However, the notion of Industry 4.0 and concept of Internet of things can be understood as availability of all relevant information in real time data by all parties involved in value creation.*

# Motivation for the research

In recent decades, the aerospace industry has become an expert in using real time data for the purpose of monitoring and maintenance scheduling, where the real time data is transfered back to manufacturer where diagnostic and prognostic analysis takes place.

Same principle is taking over the construction and automotive industries. All things been said, the lack of knowledge, technology and methodologies in monitoring and processing data from the system led authors to beleive that industrial sector is skipping a few steps and automatically implementing state-of-the-art technology forced by their CEO's.

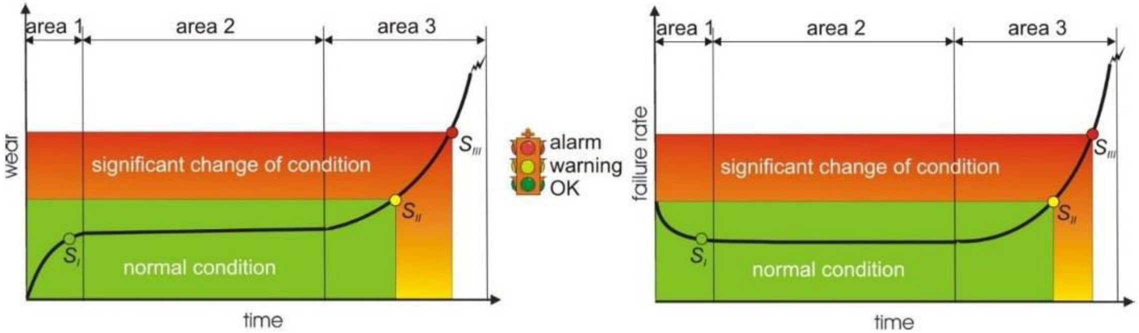
Therefore, motivation for the research was provoked by generally wrong understanding of key indicators as warning signs of contamination in hydraulic systems hence leading to inadequate monitoring techniques and inappropriate maintenance strategy.

# Contamination control in hydraulic systems

Contamination control is necessary in preserving the integrity of hydraulic systems. Contamination control is considered as a broad subject that is applicable to all material systems which goal is to maintain specified contamination level of a system.

One of the pedlars of contamination control field in maintenance of hydraulic systems, prof. E. C. Fitch, distinguished two groups of contaminants: material and energy.

There are different types of failures in hydraulic systems, depending on the wear process. For example, infant mortality or failures on the start (area 1 on picture), failure in service mode (area 2 on picture) and final mortality (area 3 on picture) with components wear out or fatigue.



# Contamination control in hydraulic systems

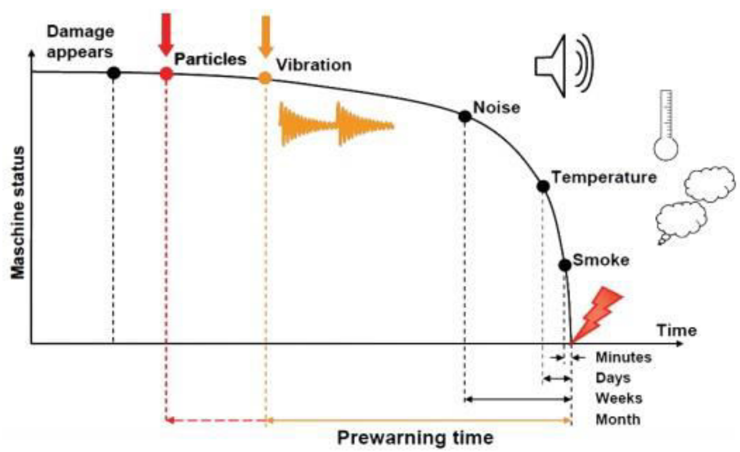
Great number of failures are caused by inadequate oil cleanliness or by wear out of components due to particle contamination. Particles and debris can enter the system in many ways, thus particle contamination sorting is given as following:

- Built-in contamination. Contaminated hydraulic system during manufacturing and assembling (welding slag, dirt and particulate) and contaminated new oil (during manufacturing, handling and storage).
- Ingressed contamination. This type of contaminants enter the system through breather cap, dirt sticking to cylinder rod, or disconecting the system for maintenance.
- Internally generated contaminants. This type of particle contamination is the most dangerous one, because it is generated due to material removal from inner surfaces of components (wear process by abrasion, adhesion, fatigue), and then circulated through the system damaging other components.

# Condition monitoring of hydraulic equipment

Condition monitoring measurements are based on application of advanced methods of signal acquisition, processing and conditioning.

Data used for diagnostics and prognostics, must be extremely well processed and accurate, in order to get a proper feedback of the system health. This is important for machines that operate under extreme conditions and stringent deadline schedules where constant monitoring of the equipment is required.
Based on montoring techniques failure can be prevented and prolonged, which depend on pre-warning signaling.

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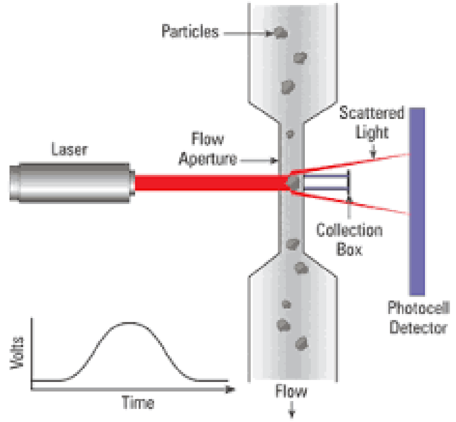
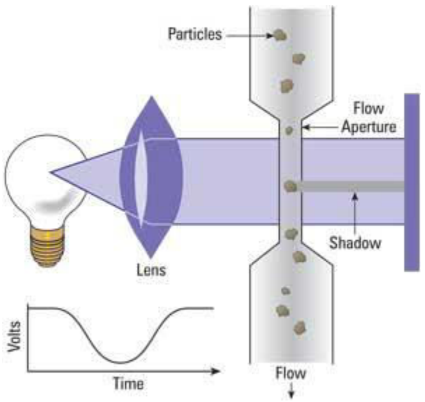
# Condition monitoring of hydraulic equipment

One of the examples is that results by inline Automatic Particle Counters (APCs) can show discrepancies up to **± 1÷2 ISO 4406:99** class level comparing to high precision laboratory instrument.

Maintaining the required cleanliness level and monitoring the filters, give information about the oil and components state. One of the simplest forms of monitoring contamination is filter bypass signal. Filter bypass-signal with differential pressure indicator (according to DIN 24550) represents the rise of captured contaminants in the system. For example **Vickers** indicators are designed to indicate at a pressure drop of **20%** below the bypass setting which equates at ***95%*** of the element's service life therefore indicating the end of service life of a filter.

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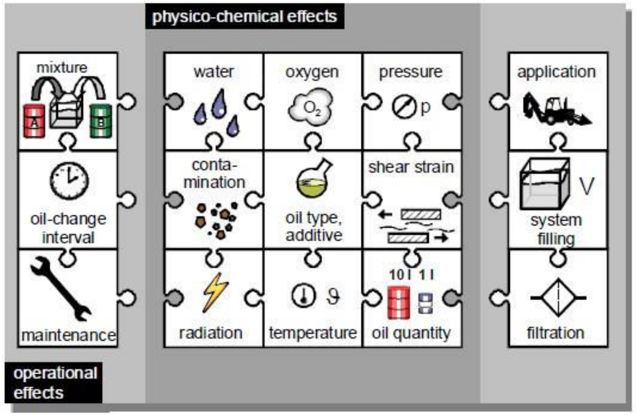
# Condition monitoring of hydraulic equipment

Based on that analysis it can be concluded which components of the system are damaged. For example, Felix Ng[1)] emphasized that iron and copper are the key indicators on hydraulic components wear rate, which was concluded by ICP/OES analysis of oil in the excavator.

Considering the importance of measuring the desired parameters of the system, maintenance managers and engineers can determine the sensors needed. Some authors advocate that the priority sensors should be particle counters, although authors of this paper propose than in some cases other sensors can give even earlier signs of system performance degradation.




*1)* Ng, F., Harding, J.A., Glass, J., (2017) Improving hydraulic excavator performance through in line hydraulic oil contamination monitoring. Mechanical Systems and Signal Processing, vol. 83, pp.176-193.

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# Condition monitoring of hydraulic equipment

Taking into account that real-time data measurements are needed with equipment working around-the-clock laboratories cannot be considered in data management, and the reason is time limitation. Stoppage in industrial machinery is directly related to loss of production and expences. However, using online sensoring can provide trend analysis, while laboratory procedures provides detailed information needed to analyze the trend.

Whilst automatic particle counter can play a significant role in early detection of wear in hydraulic system, authors propose that trend analysis from viscosity also can play a crucial role of pre warning sign. This can be done by measuring viscosity by an inline viscosity instruments

# Discussion

As mentioned, not all conditions, which are influenced by external or internal problems, may lead to failure due to particle contamination as a root cause. Sufficient portion of that can be attributedto viscosity drop by contamination.

The drop in viscosity, which is influenced by many factors, can lead to metal-metal contact within and among the hydraulic system components. Critical components like the hydraulic pump suffer the most duering this wear process. Therefore, a distinction should be made between pre-warning signs of potential failure.

Since the viscosity is a measure of fluids' internal friction or its fluidity: its resistance to flow reflects the response of a system, because the fluid is the one transfering the energy from mechanical – hydraulic – mechanical. Changes in viscosity affects performance of a system because the physical properties of the oil changes due to change in viscosity. Among other physical stability properties of a fluid, viscosity and viscosity index are considering the most important ones in hydraulic fluids.

# Discussion

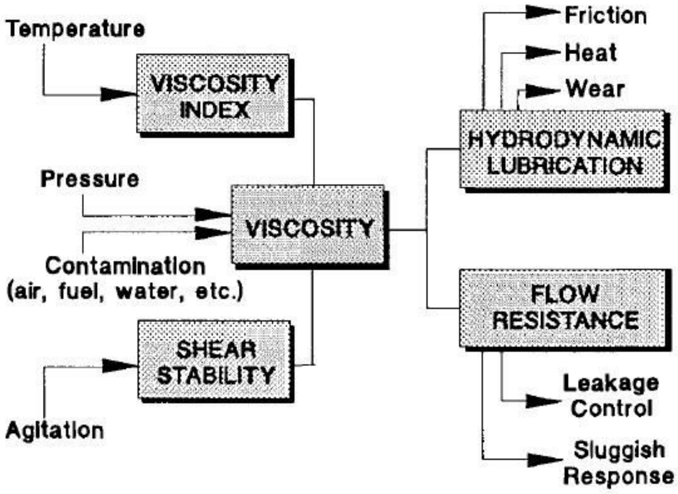
Viscosity, depending on temperature, pressure and contamination, can rise or fall. Excessively high viscosity can produce several system problems, such as: high pressure drops, pump cavitation, high power consumption, etc.

As oil viscosity decreases, the lubricating film thickness decreases leading to metal-to-metal contact and wear occurs within that contact pair. Hence, particles rise which can be followed by more damage from other components, while that wear debriss is circulating throughout the system.
Since the temperature is cosidered the most damaging parameter affecting viscosity, engineers and managers usually implement components like heat exchangers in critical systems.

# Discussion

A simple illustration of viscosity influences are given in picture. Another thing that shouldn't be left out of the discussion is the Viscosity Index. Most of the component manufacturers demand specific viscosity and viscosity index for a given application or the specific component.

Viscosity index is a measure of fluid's viscosity in regard to temperature change. Thus, considering the application and the working environment users should consider both parameters.

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# Discussion

Limits for changes in the viscosity depend on the type of lubricant being analyzed but most often have a marginal limit of approximately 10% and a critical limit of approximately 20% higher or lower than the intended viscosity.

Another method is seen by measuring Total acid number (TAN) or base number. Acid number and base number tests are similar but are used to interpret different lubricant and contaminant-related questions. In an oil analysis test, the acid number is the concentration of acids in the oil, while the base number is the reserve of alkalinity in the oil.

Taking into account zinc dialkyldithiophosphate (ZDDP), additive that improves antiwear (AW) properties of the oil, can deplete and cause oil film to breakdown afterwhich metal-to-metal contact will occur at high pressures. Therefore, viscosity changes within the systems are linked to additive depletion also.

# Conclusion

Firstly and foremost, this research was done to draw the attention of maintenance personnel and system users on the importance of condition based maintenance and monitoring techniques.

Authors of the paper presented the types of contamination in hydraulic systems, and agree that particle contamination is  the most damaging one in the sense of causing wear of hydraulic components.

However, other types of contamination (especially water) are influencing the degradation of physico-chemical characteristics of the oil. In response to that, different type of monitoring techniques and on-line instruments should be used.

Noticing the fact that rise of particles within the system are used as pre-warning sign of failure  is disputable, therefore integrating monitoring of other parameters is advanced. If one consideres the rise of water content in the fluid as a pre-warning that failure or wear in the system may occur, the same could be used as an early signal.

# Conclusion

Since the industry 4.0 is demanding real-time data measurement, it is good to use data from signal processing and trend analysis like on-line instruments (APCs, flow, temperature, pressure, etc) but authors also propose using instruments for measuring viscosity and/or water presence in early detection by viscometers and trend analysis performed againist thresholds.

In order for oil analysis report to be effective authors advocate that limits and thresholds for trend analysis of online measurement should be confirmed or combined with off-line laboratory diagnostics. In that way results can be more accurate and reliable.

Another important thing to point out, while performing on-line measurements in order to acquire real-time data, engineer or technician must not use only data from trend analysis of one specific measurement in terms of data, but rather focus on more inter-related parameters using prediction modeling to reduce risk of failure or system stoppage.

# THANK YOU FOR YOUR ATTENTION!