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Energy Intensive Process in Professional Laundry Service: Up-to-date Approach

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This paper deals with long-term research activities related to energy, water and detergent consumption in industrial laundries and related energy intensive processes. An original approach consists of analysis of all the process in a professional laundry. The aim is to target possible energy savings and low potential heat utilization. In-house software for simulation was used for this purpose. Since this W2E (Waste to Energy) software was created as open source it was adapted for the purpose of simulation in process and power industry in various types of energy intensive processes. The most energy consuming equipment was identified and the process as a whole as well as individual apparatuses was investigated. The computational approach was supported by measurements in real facilities. This effort continued and laundry of the future was designed. This laundry enables testing of various operational regimes, verification of models, improving of key equipment design, and also comparing efficiency of processes using various detergents and economic analyses.
Professional laundry process involves implementation of energy efficient technologies; however, being lack of operational data is a common feature. Therefore the first testing laundry was built in NETME Centre. It represents a unique technology which enables to analyse the operational costs comprising:

- Water, energy and chemicals costs
- Direct labour costs
- Costs of transport

Further, economics in this field in various European countries based on specific factors was evaluated.
Recent research activities lead to development of an original comprehensive approach. This approach utilizes experience and know-how from analyses of various energy demanding processes both in the process and energy industries as well as municipal sphere. It is also based on using sophisticated computational methods (simulation of heat and mass balance, CFD simulation, equipment modelling, experimental data processing, modelling of economics). Credible data are acquired from operation of up-to-date testing laundry. Then it is possible to analyse the system quite thoroughly and provide manufacturers of equipment, manufacturers of detergents, operators and investors as well as the customers and linen testing institutes with valuable data and recommendations.

1. Professional laundry service

The category of the so called "low capacity laundries" where the capacity reaches the maximum of 300 - 500 kg of linen per shift (8 h) is dealt with in this paper. These laundries operate batch washers and dryers with low capacity up to 8 - 12 kg. Flat linen is ironed using cylinder-heated ironers (the so-called mangles). Garments are ironed using ironing presses. Low capacity is the most common category of laundries in Europe. It is readily suitable to wash linen from hotels, production plants, dormitories and students cafeterias. Effective automatic washing has been around since 1950s when the first automated washing machine launched the market. Let us look back on a history of laundry care from the very beginnings. Ancient period started with highly inefficient and time-demanding washing of linen in rivers. Milestones of laundry care are marked with first use of warm water and soap. Invention of scrub board is another important break-through in laundry care. Mechanical manual washing machine and mangle were

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developed in mid 19-th century. Manual drive of these devices was substituted with electricity at the turn of 20-th century. First electrical dryer followed ten years later. Development of chemistry during First World War resulted in production of new synthetic washing detergents which were broadly put in use many years later. First automatic washing machine was introduced in 1950s as mentioned above (Procter & Gamble, 2012). At present, information technologies (IT) have the most significant impact on development of laundry service, especially in application of IT in the control of the process.
Typical workflow of recent laundry facility consists of three sub-operations of professional laundry: washing, drying and ironing. These are conducted in superior industrial machines. Operation of these industrial machines is closely related to consumption of thermal and electrical energy and water, of course. Basic elements of today's laundry process are shown in Figure 1: raw materials (left), products (right), resources and consumables (top) and wastes (bottom).

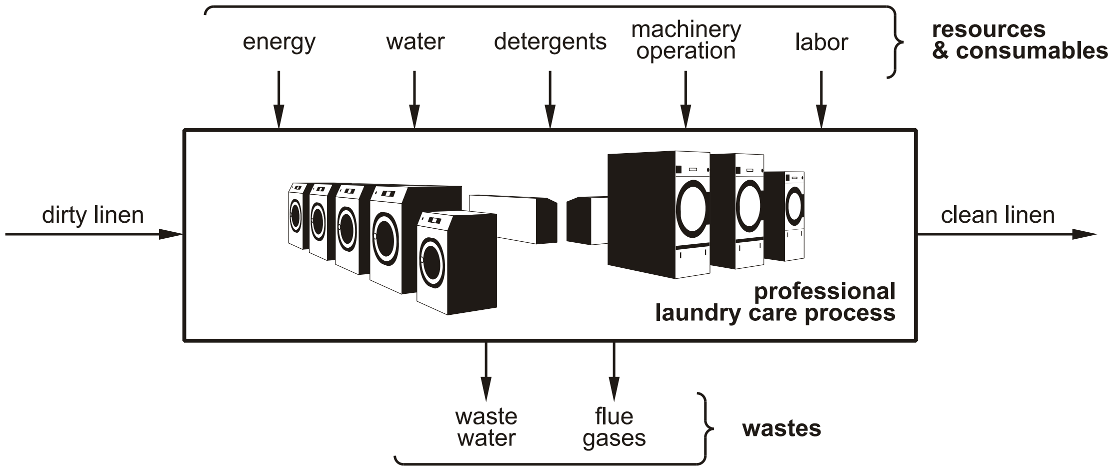

Figure 1: Basic process diagram of professional laundry service process

Energy intensity of washing process is given by amount of energy used for heating the washing water. Approximately 13 L of fresh water, 0.2 kWh of heat and 0.1 kWh of electrical energy are consumed so that 1 kg of laundry in a modern industrial laundry of low-capacity (300 – 500 kg of laundry per 1 shift) is washed. Large amount of electrical energy and natural gas are further used to heat drying air. In addition to that, much of the energy leaves the process in waste flows completely without any profit (Máša et al., 2013).
European corporations and academic researchers are well aware of the fact that it is crucial to achieve energy savings in industrial plants (Darabnia et al., 2013). This also applies to laundry care businesses and increasing energy efficiency of laundry machines. Various energy efficient and environmentally friendly measures for washing, drying and ironing are researched and developed constantly. However, few businesses are able to provide complex solution to energy and water management in the whole facility. This is where the academic institutes enter the scene since the businesses and laundry facilities operators are keen to cooperate and develop solutions to this type of multiple tasks. It was found out that there is no consistent research of energy efficiency and environmentally friendly measures in laundry service. This fact is substantiated by absence of relevant scientific literature and lack of applicable methodologies and regulations providing for long-term sustainability of laundry facilities. Extensive research study has proved that there is no relevant scientific engagement in this field despite the fact that laundry industry is very interesting from the scientific point of view (Máša et al. 2013). Success in research is conditioned by knowledge from power industry, environmental protection, information technologies, machine design and others. It comes from highly multidisciplinary character of this topic. Present activities of research that applies complex and sophisticated approach to laundry service are presented in the paper. These activities were greatly enhanced by construction of Laboratory of energy intensive processes (NETME Centre), world unique research facility that focuses on energy efficiency and environmental impact of laundry industry.

2. Up-to-date approach

Well optimized energy consumption of each stand-alone machine does not always stand for the lowest amount of required energy on the whole. This fact is mirrored in a situation when even the best individuals not always make up the best team. Therefore, the best practise to decrease energy consumption is to look at the process as a whole and utilize energy of all available hot streams while still keeping the whole solution profitable (Bobák et al., 2010). A complex analysis of all the laundry processes is essential. Basic steps of up-to-date approach are as follows:

- Deeper understanding of the process in question
- Acquisition of operational data
- Data processing supported by computational tools
- Design of energy efficient and environmentally friendly solution

2.1 Deeper understanding the process in question

Research team conducted several successful optimization studies aiming at functional properties of machines for various producers of laundry machinery. Optimization concerned operation of continuous batch washers and dryers, application and control of heat recovery systems or optimization of the air flow in the vacuum channel of the ironer. This optimization task greatly supported the current knowledge and know-how of laundry technologies and production procedures. The most energy consuming equipment was identified and the whole process and individual pieces of equipment were investigated. The basic condition for low energy consumption is optimization of water management because lower consumption of water goes hand in hand with lower energy necessary for its heating. Two most important parameters of dryer and ironer are their real specific energy consumption and drying capacity (Bobák et al., 2010). Values of all the parameters usually can be found in technical documentation of each machine but real operational values often differ from values provided by manufacturer.

2.2 Acquisition of operational data

Extensive measurements were conducted in several European laundry facilities so that declared consumption of washing, drying and ironing processes may be verified. Each laundry facility has its own unique operating conditions that have to be considered in data acquisition. Common impediment of the data collection is a limited measurement system. Individual consumption of water, electrical energy, steam, natural gas, and detergents are the most important parameters which are rarely measured. Operators are familiar with consumption of the facility thanks to billing meters and reading is commonly performed only once every billing period. Consequently, there is a lack of data where and how efficiently energy and materials are consumed (Máša et al., 2013). Therefore, portable measuring devices are commonly preferred. Devices must comply with high standards for reliability and accuracy. At the same time, they must be compact and portable. Instalment of most of the sensors constitutes interference into existing technologies and quite frequently discontinuation of operation.

2.3 Data processing supported by computational tools

Data processing is closely related to theoretical knowledge of laundry care process. High quality analysis of machine energy intensity should be based on mathematical description (model). Experimental data is used to specify these theoretical models. Equipment as well as the whole facility may be subjected to modelling. Computational tools come in handy here. It is a great advantage if the tool may be customized for a specific task. New computational tool which enables to analyse flows of energy through the professional laundry service from utilities to every consumer was introduced by Bobák et al. (2011). This is in-house simulation software originally created for waste-to-energy applications. This is also where the name Waste to Energy (W2E) comes from. Software was introduced by Touš et al. (2009). Core advantage consists in monitoring and comparison of effects of different operational regimes (Kropáč et al., 2011). Results are useful for techno-economic analysis of laundry service and software may thus be used as a support in decision making process. Software support is also indispensable in processing data related to fluid flows and heat transfer. This can be carried out using computational fluid dynamics (CFD) approach.

2.4 Design of energy efficient and environmentally friendly solution

Design of specific solution is a final phase that may be targeted at the production plant and/or laundry facility operator. Laundry equipment producers and laundry detergents producers have extensive knowledge of laundry technologies. Their main objective is to innovate individual pieces of equipment. Cooperation with laundry operators is a must because they have everyday contact with the laundry and may provide valid operational data. Laundry facility operators' objective is to increase efficiency of the whole process. Specific solution was presented by Máša et al. (2013) which basically comprise

implementation of heat recovery systems, water management and increase in productivity of human labour. Bobák et al. (2012) focuses on heat recovery in laundry facilities. It is obvious that each design of heat recovery systems must be customized to meet specific local conditions of the facility. Máša et al. (2013) proved that energy efficiency measures may have significantly different economic impact in various European countries. Environmental impact assessment cannot be neglected.
Up-to-date approach therefore consists of a complex analysis of the whole laundry process and application of the state-of-the-art methods and technologies. Successful development and implementation of energy efficiency measures in laundry services are conditioned by long-term and systematic research of laundry care.

3. Research facility

Recently built NETME Centre (New Technologies for Mechanical Engineering) - a regional research and development centre at the Faculty of Mechanical Engineering at the Brno University of Technology – enables to perform a systematic research of professional laundry care process. Centre operates a unique laboratory combining a real laundry facility with capacity of 500 kg of linen per shift with superior research equipment. Research model of professional laundry care process will be fully functional as a real laundry facility and will allow for analysis of the process and its optimization in authentic premises.
Mission of the research team is to help an industrial process with minimization of wastes, high efficiency of energy utilization, minimum environmental impact, and outstanding quality of the linen and advanced stage of automation. This is the so called "laundry of the future" (Figure 2). Introduced vision is supported with modern equipment, infrastructure, measurement system and related technologies.

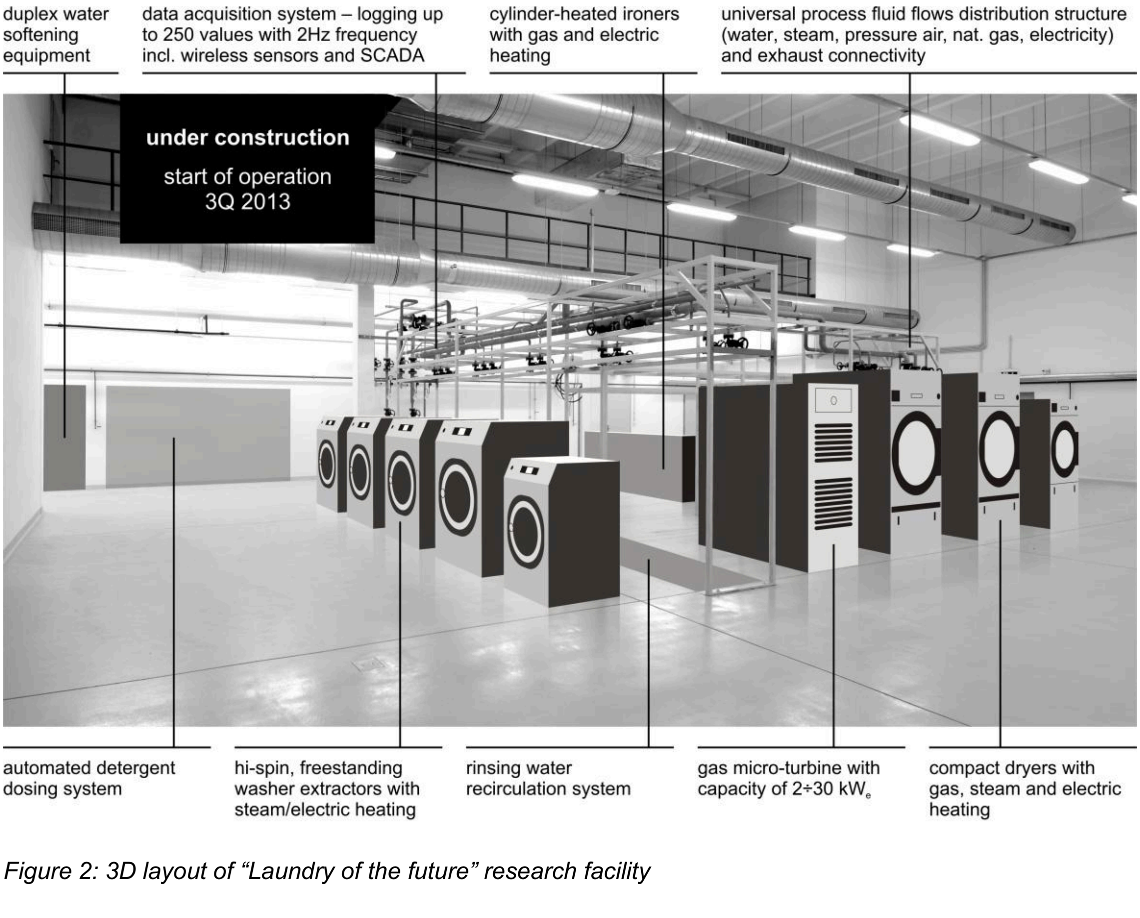

Figure 2: 3D layout of “Laundry of the future” research facility

3.1 Machines

These are the core technological components available in the laboratory “laundry of the future” (Figure 2):

- Five washer extractors with combined heating (electricity and steam), total capacity 92 kg of dry linen. Washing machines are equipped with automated detergent dosing system.

- Three compact dryers with total capacity of 64 kg of dry linen. Each of the installed dryers has a different heating system (steam, natural gas, electricity) allowing for comparison.
- Two cylinder heated ironers (mangles) with identical size, electrical and gas heating and smaller ironing press with steam heating.

This machinery reflects equipment in recent laundry facilities with 500 kg per shift capacity. Technological equipment was further extended with necessary accessories such as manual ironer, sewing machine, transport trolleys, etc.

3.2 Universal infrastructure

Flexible connection of all the above mentioned machines requires instalment of infrastructure. Steel structure is located in the laboratory and connects inlets for fluid flows, waste, exhaust, and elements for analysis of operational characteristics (see process fluid flows distribution system in Figure 2). 18 independent sites are located around this structure where various energy intensive appliances may be tested (e.g. reactors, dishwashers, sterilizers, etc.).

Water is the main process fluid in the research facility. Raw water is commonly softened in modern industrial laundries and therefore a water treatment facility is also operated (Figure 2, left). Electrical energy and natural gas are supplied at each station in addition to steam of two pressure levels: 8 bar(g) and 0.3÷1 bar(g) and pressure air.

3.3 Measurement and data acquisition system

Measurement system has to be highly flexible. Therefore, infrastructure is enhanced with universal instalment set for attachment of various measuring elements. Collected data are gathered in hardware which a programmable logical controller allowing to sense up to 250 values with 2Hz frequency. All individual machines (monitoring of state) and all sensors are attached to the controller. Measurement system comprises following measuring elements:

- electricity meters, gas meters, magnetic flow meters, turbine flow meters (consumption of resources),
- orifice plate flow meter with differential pressure gauges, absolute pressure gauges and thermometers (consumption of steam),
- platform scale and bench scale (weighting of linen),
- strain gauges in machine base (weighting of linen inside of machines),
- Prandtl tubes with differential pressure gauges and relative moisture meters (chimney heat loss),
- resistance thermometers PT100/PT1000 and temperature gauge (temperature of water and gases),
- thermocouples (measurement of temperature of heat exposed parts of machines),
- strain gauges (measurement of deformation and stress of selected parts of machines),
- electrical conductivity meter (conductivity of washing bath).

Measured data are transferred from measuring hardware via local ethernet network into the server. Server runs software for visualization and storage of the data. Data are stored in network attached storage (NAS) with disc field in RAID1 configuration (data mirroring).

3.4 Other up-to-date technologies

Gas microturbine is also part of the laboratory machinery and is used as a generator of dry air (up to 90 kWt) and electrical energy (up to 28 kWe). Microturbine will serve for testing of cogeneration in laundry service. Flue gas coming from turbines may be a drying medium in dryers (Figure 2, right).

Measurement system was supplemented with wireless sensor network (WSN) which comprises 6 sensor nodes. These nodes use wireless technology to communicate with base station and with each other via radio waves of 2.4 GHz and help measurings in out-of-reach places, such as in a drum of a washing machine or dryer. Use of WSN is also favourable in short-term and long-term collection of data in real professional laundries thanks to the speed of instalment.

Additionally, a supervisory control and data acquisition system (SCADA) is used. It is installed on the server to review and visualise the whole process. Graphics output within the the laundry premises is delivered via all-in-one computers and/or wirelessly on tablets. This measure enables flexible review of particular technologies during operational testing and also in education.

4. Research task and expected deliverables

The research facility background described above provides us with optimum conditions for application of complex up-to-date approach. First step in research tasks will focus on analyses of consumption of energy intensive appliances. This should bring precise mathematical models of all of facility machines and laundry processes. Research activities cover following directions:

(i) Design of appropriate construction and technological adjustments of particular machines with the help of computational tools. The objective consists in reducing energy and media consumption and environmental impact. Close cooperation with laundry equipment producers provides us with valuable background in terms of real outputs.

(ii) Thanks to experimental operational testing of energy intensive process it is possible to design energy efficient measures that optimize operational costs of the process. At the same time there is focus on maintaining low environmental impact of the process (optimized use of energy resources) and decrease of produced waste flows. This research and its results are highly beneficial for laundry facility operators.

(iii) Cooperation with manufacturers of detergents and linen testing institutes. Laboratory infrastructure and multidisciplinary character of the research can enable applications in other research and development areas in the future.

5. Conclusion

Professional laundry service is an energy intensive process with high potential of implementation of various economic measures. However, implementation is conditioned by sufficient amount of experimental data so that theoretical assumptions of the process and technologies may be reliably verified. Therefore the first testing laundry was built in the NETME Centre, research and development centre. It represents a unique technology which enables testing of machines and credible data acquisition. Original comprehensive approach was developed. This up-to-date approach utilizes experience and know-how from many European laundries and manufacturing companies and engages computational tools for optimization of the process.

Combination of superior research facility and up-to-date approach provides for high quality analyses of the system. Industrial partners may benefit from valuable data and solutions. Strong emphasis is laid to optimization of operational costs of laundries and reduction of laundry care environmental impact. Hand in hand with process optimization and costs reduction, it is necessary to maintain top quality of the laundry service.

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