WEB BASED CUTTING FLUID EVALUATION SOFTWARE

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ABSTRACT

There is increasing concern for the significant cost and negative environmental and health effects associated with cutting fluid usage. In addition, there is lack of knowledge regarding selection and application of cutting fluids. The development of a Cutting Fluid Evaluation Software Testbed (CFEST, Ver. 2.0) under the aegis of Machine Tool-Agile Manufacturing Research Institute attempts to address this issue [10]. This web-based software provides quantitative information regarding cutting fluid performance, environmental impact, health and safety hazards [9], and costs for cutting fluid comparison and selection. The CFEST software modules reside on servers at three different geographical locations, forming a distributed system. The data is transferred within the distributed system using a Data Transfer Mechanism (DTM). A description of the structure of CFEST, its modules, and the DTM is presented.

INTRODUCTION

The waste stream generated due to cutting fluid usage is a cause of great concern to many manufacturers. With environmental regulations becoming stricter, industries are forced to treat waste fluids before disposal. There is also concern about the exposure to cutting fluids and the mist generated from them in terms of producing skin and respiratory diseases and even cancer. The mandatory maintenance and treatment of the cutting fluid and the usage of mist collectors to prevent harmful environment and health impact add up to a significant cost. The Cutting Fluid Evaluation Software Testbed (CFEST) is one of the software testbeds being developed by the Machine Tool-Agile Manufacturing Research Institute (MT-AMRI). The purpose of this software is to provide an analytical cutting fluid evaluation tool. Users access the software interface over the Internet through a PC, or workstation using a browser such as Netscape. The users fill out forms in the user interface to input information regarding cutting fluid type, application method, machining parameters, and site specific factors and send out a request for running the software testbed. After running CFEST, the users receive output in the form of Hypertext Markup Language (HTML) text and/or graphs. The output gives quantitative information regarding the cutting fluid's process performance, environmental impact, health and safety hazard scoring, and the costs for procurement as well as for treatment. CFEST uses experimentally measured thermophysical properties [4] of cutting fluids stored in a database along with analytical models to predict the results. A Data Transfer Mechanism (DTM) developed at the University of Illinois at Urbana-Champaign [12] is used to transfer data over the Internet between different modules residing at different geographical locations. At present the CFEST can be used to:

1. Obtain all the outputs for the turning process with flood and jet application of cutting fluid.
2. Compare torques and axial forces in tapping process with and without cutting fluid.
3. Estimate the temperature distribution in boring with and without cutting fluid in a cylinder boring process.

CFEST STRUCTURE

A software testbed is a web based application that allows clients to access a group of programs on remote servers over the internet, communicate a set instructions to the programs, and bring back the output of the program to the clients. Figure 1 depicts the remotely accessible web-based CFEST. It consists of process performance modules residing at Michigan Technological University (MTU), a fluid disposal impact module residing at University of Illinois at Urbana - Champaign (UIUC), and a health and safety hazards module at University of California at Berkeley (UCB). The three servers in CFEST form a distributed system. In a distributed system, the existence of multiple autonomous
computers is transparent to the user. For example, a client can give a request to run a program, it is then up to the operating system to select the appropriate processor, find and transport all the input files to that processor and put the results in the appropriate place. In other words, the user is unaware that there are multiple processors; it looks like a virtual uniprocessor. In effect, a distributed system is a software system built on top of a network. A DTM developed at UIUC is used to transfer data in the distributed system. Users can access the comprehensive software through a single Universal Resource Locator (URL) address [13], and the output results from different modules are brought together by the program manager in a comprehensive way before presentation to the users.

FIG. 1: DISTRIBUTED SOFTWARE TESTBED AND REMOTE ACCESS

CFEST MODULES

There are three modules in CFEST. The process performance modules (developed by MTU) within CFEST predict the heat generation, heat transfer, mist generation and chip carry-off characteristics of the cutting fluid/process condition combinations. The health hazard scoring module established at UCB provides an assessment of the in-plant impact of the process. The UIUC fluid disposal impact module estimates resource consumption and pollutant loadings of the fluid. Figure 2 shows the structure of the distributed software testbed. A brief description of each module is provided below.

FIG. 2: MODULES AND STRUCTURE OF CFEST

Process Performance Modules

Heat Generation Model. Heat is generated at the cutting zone during a machining operation. In CFEST, the prediction of the strength of heat sources is based on submodels for cutting force prediction and shear angle prediction. For a user defined cutting tool geometry, an effective orthogonal cutting plane may be defined as a plane containing the cutting velocity vector and the chip velocity vector [9]. In this plane, empirical models are used to predict the cutting and thrust forces. To predict the heat generated in the shear zone and at the chip/tool interface requires knowledge of the forces acting on the shear zone and between the tool and chip. To determine these forces, a value for the shear angle is needed. This is calculated based on the predictive model described by Wright [9]. The generated per unit area in the shear plane and over the chip/tool interface can now be calculated.

Fluid Heat Transfer Model. Heat transfer from the workpiece to the fluid is primarily by forced convection with either laminar or turbulent boundary layers depending on the relative velocity of the fluid. The Nusselt number for a given set of conditions can be calculated using empirical correlations available from the heat transfer literature. From the Nusselt number, the heat transfer coefficient may then be computed provided the thermophysical properties of the cutting fluid are known.

A database of cutting fluid properties provides necessary data to the various modules in CFEST. Fluid viscosity, density, surface tension, specific heat, and thermal conductivity were experimentally determined and stored as a function of cutting fluid type, concentration and temperature [4].

A model for heat transfer in a turning operation flooded with cutting fluid requires a correlation for forced convective heat transfer from a rotating cylindrical surface to a fluid in transverse flow. A Nusselt number correlation [7] with these effects involves two Reynolds numbers; the first takes into account the effect of workpiece rotation and the second accounts for the effect of transverse fluid flow. For a jet application of cutting fluid on the workpiece, a similar correlation for the Nusselt number [8] is used in the CFEST heat transfer model.

The heat transfer module within CFEST accesses fluid thermophysical properties for the selected fluid from the database and computes the heat transfer coefficient for the process. A comparison of the heat transfer rates with different fluids (and also with air as for dry machining) is provided. CFEST also includes heat transfer models for cylindrical boring processes which evaluates temperature distribution in a cylinder under dry and wet machining conditions.

Fluid Carry-off Model. The amount of cutting fluid carried by a unit chip surface area is dependent on the surface tension of the cutting fluid, the contact angle between the coolant and the chip, and the average radius of the coolant drop adhering to the chip. A semi-empirical model was proposed by Adamson [1] to predict contact angle from the surface tensions for the solid, the surface tension for the fluid, and absorption effects of the solid. CFEST assumes that sessile drops and suspension drops are formed and distributed uniformly over the entire surface of chip. The total amount of cutting fluid carried off by the chips can be estimated as the product of the total surface area of chip and the 'm' value.

Fluid Mist Model. A mist waste stream is often generated in machining processes with flood-cooling or jet-cooling. Fluid mist
formed and not sufficiently captured can remain suspended in the air for many hours and negatively impact the health of workers. Research in mist formation indicates that the heat generated in machining may vaporize the cutting fluids and subsequently form the mist by condensation. Also, mist can be formed through atomization [2]. At present, CFEST uses a model for mist formation through atomization. Two basic modes of atomization have been modeled and implemented into CFEST: drop mode and ligament formation mode. Drop mode mist formation occurs at low cutting fluid flow rates, and ligaments are formed due to wave disturbances at higher flow rates. Many unstable ligaments appear at the circumference and break up into small droplets. Mist formation model in CFEST assumes that mist droplet size is affected by the cutting fluid application strategies, fluid physical properties, and cutting conditions [15]. When the user inputs these parameters into CFEST, mist droplet size can be calculated.

**Fluid Disposal Impact Module**

As one of the main goals of the MTAMRI is to integrate research carried out at participating universities, CFEST includes a software module developed at UIUC that predicts pollutant levels associated with cutting fluid discharges. Given process parameters such as cutting fluid type, dilution, quantity of process wastewater discharged, and the total quantity of plant wastewater into which the process wastewater is diluted, this module of CFEST calculates the pollutant rate leaving the machine tool and its contribution to an increase in the total pollution rate leaving the plant.

There are many general types of pollutants which might be of concern in terms of waste water treatment [5]. These include soluble organics causing biochemical oxygen demand (BOD), fats oils and greases (FOG), nitrogen and phosphorous, suspended solids, trace organics, heavy metals, cyanide and toxic organics, color and turbidity, refractory substances resistant to biodegradation, and volatile materials. CFEST presently accounts for BOD, FOG, nitrogen, and phosphorous pollutants in cutting fluids.

Since most of the waste fluids are required by law to be treated prior to disposal and all treatments have costs associated with them, it is reasonable to use a metric of dollars to account for the environmental impacts of BOD, FOG, nitrogen, and phosphates. The software module estimates reductions in BOD and FOG due to these pre-treatments using values reported in the literature. However it is important to recall that actual pollutant reductions vary significantly from plant to plant, and these estimates are averages meant to give an idea of the final pollutant loadings expected. In cases where pre-treatment and/or disposal cost rates are known, CFEST also calculates the incremental increase in total disposal cost due to the cutting fluid system being analyzed. Thus both the pollutant loadings and disposal costs can be used as metrics to internalize the environmental impacts of BOD, FOG, nitrates, and phosphates. Further research is being conducted to improve this module in future versions of CFEST.

**Fluid Health Hazard Scoring Module**

With the increasing concern for the potential health hazards to workers exposed to cutting fluid waste streams, different states of the waste streams and their impacts on the health and safety of operators need to be analyzed when making fluid selection decisions. The CFEST fluid health hazard scoring module being developed at UCB provides an "in-situ" hazards evaluation tool for such a purpose. Cutting fluid health hazards are evaluated at process level and facility level. The evaluation results are integrated into a composite Health Hazard Score (HHS). At the process level, depending on the chemical species and physical phases, the different forms of product and catalytic waste streams will have different environmental impacts. Within the process-level control volume, the acute factors of concern include oral toxicity (O), dermal irritation (D), eye irritation (E), reactivity (R) and flammability (F) [Srinivasan et al. 1995]. A problem in applying a multi-variable evaluation is the different levels of data certainty and aggregation along these seven factors. A categorical scale can be implemented to create a 7 × 1 row vector of hazard subscores [Srinivasan et al. 1995]. Each element score is on a scale of 0 to 9. In the case of O, I, E, D, this value is obtained by multiplying a dose score by an effect score. C is scored by the degree of evidence of oncogenic potential and R is scored according to the fluid's reactivity with different substances. The F score is obtained through a multiplication of a flashpoint score by a explosion limit range score.

To introduce phase effects into the chemical hazard subscores, a phase matrix is constructed which partitions each factor among the different physical phases. For example, for inhalation toxicity, the overall hazard score of 1 can be partitioned into the following:

- Solid: 0.8
- Liquid: 0.2
- Aerosol: 0.5
- Vapor: 0.3
- Particulate: 0.2

Using this approach, different phase vectors for solid, liquid, vapor, aerosol and particulate phases can be generated [Srinivasan et al. 1995]. This HP vector (where \( H_{ij} = Dose_{ij} \times Effect\times Phase\)) represents an effects-based multi-criteria measure of environmental effects.

The data requirements for constructing the HP vector include information from sources such as material safety data sheet (MSDS), registry of toxic effects of chemical substances (RTEDS), ACGIH-HLV data, Centers for Disease Control (CDC) studies, and other public-domain information. This effect based metric can be applied to evaluate the "quality" of waste stream emanating from a particular manufacturing process.

At the production planning level, the HP vector metric described above is incomplete in as far as it does not account for site-specific factors which may influence fate and transport of specific waste stream. One method for accounting for site-specific factors is to establish a facility vector, \( F \), which incorporates issues such as workplace practices, protective gear, auxiliary equipment and post-processing, equipment and machinery selection, and facilities design. Two approaches for constructing the \( F \) vector are presented by Gune and Shen [1995].

Once the \( F \) vector has been determined, a composite score, Health Hazard Score (HHS), can be calculated as:

\[ HHS = HP \cdot F \]  

(1)

The HHS score can either be used as an indicator of "in-situ" effect of a waste stream or as a weighting factor for mass flow through a process through:

\[ m_{w} = m \cdot (HHS) \]  

(2)

where \( m_{w} \) is the environmental-weighted mass flow and \( m \) is the raw mass flow. To assess the quality of aggregate output massflows from a facility, multiple HHS values can be calculated:

\[ m_{w, j} = \sum m_{j} \cdot (HHS_{j}) \]  

(3)

where \( m_{w, j} \) is the weighted mass flow for the facility, \( m_{j} \) is the raw mass flow for the jth chemical species analyzed, and \( HHS_{j} \) is the health hazard score for the jth species. With fluid data and
site specific data as inputs to the health impact module of CFEST, the Health Hazard Scores and environmental-weighted massflow can be predicted.

DATA TRANSFER MECHANISM

DTM is a message passing library, designed to allow computer applications running on a variety of platforms to share data [12]. It is designed to simplify the task of interprocess communication and to facilitate the creation of sophisticated distributed applications in a heterogeneous environment. To accomplish this, DTM provides a method of interconnecting applications at run-time and provides reliable message passing complete with synchronization and transparent data conversion. DTM has been optimized for large messages (100 Kilobytes and up), but is efficient for smaller messages as well. DTM provides the concepts of input and output “ports,” to which messages may be sent and received.

DTM Messages. A DTM message consists of a series of blocks. A block contains the block length in bytes followed by the data. The first block of a message represents the message header. It contains information about the attributes of data stored in the data section. Optional information may include the type of the data (char, int, float, etc.), a title, dimensions, or any other information relevant for interpreting the data section. The remaining blocks represent the data section of the message as shown in Figure 3. The end of a message is indicated through the use of a zero length block. The sender is allowed to send many data blocks of any size, but the receiver reads the data in a convenient size. In other words, the header is sent or received in its entirety while the data section may be partially sent or received. To prevent round trip latency or delay in response, in interactive applications, DTM sends a “Request-To-Send” (RTS) flag along with the header block to the destined server. The receiver will respond with a ‘Clear-To-Send’ (CTS) flag following the transmission of the RTS and the header, or even following the entire message.

DTM Port. A DTM port is an electrical interface through which the machine communicates with other machine(s) or network(s). Since DTM ports are unidirectional, the ports are specified as input or an output port when they are created. DTM ports support multiple fan-in and fan-out, i.e., an output port is capable of sending messages to multiple receiver applications while the input port is capable of accepting messages from multiple sending applications, e.g., in CFEST, the results from the UIUC and UCB servers are received on the same input port on the MTU server. Each DTM port has an unique address. For input ports, the address represents the port from which it receives message. For output ports, the address represents the location where the port attempts to connect.

![FIGURE 3: DTM MESSAGE](image)

**FIG. 3: DTM MESSAGE**

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SUMMARY

A web-based Cutting Fluid Evaluation Software Testbed (CFEST) is being developed by three participating MT-AMR/Universities, Michigan Technological University, the University of Illinois at Urbana-Champaign, and the University of California - Berkeley. CFEST consists of several cutting fluid evaluation modules that are seamlessly linked over the Internet by the program manager of the testbed. This linkage utilizes a Data Transfer Mechanism which optimizes the message transfer procedure. The software can be accessed via the Internet using a web browser. When machining parameters, fluid and site-specific data are supplied, the software returns quantitative output regarding the fluid’s process performance, cost, environmental impact and health hazards associated with cutting fluid usage. The input and output in the CFEST appears similar to as shown in the Figure 4 and 5. This software testbed provides an analytical cutting fluid evaluation tool for manufacturing practitioners to compare and select cutting fluids for better process performance while minimizing environmental and health impact.

ACKNOWLEDGEMENTS

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REFERENCES:

15. Yue, Y., J. W. Sutherland, and W. W. Olson, “Cutting Fluid Mist