Report of Cooperative Education

Optimization of Flushing Oil Quantity Used in Filling Line of Lubricant Production Plant

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Cooperative Title : Optimization of Flushing Oil Quantity Used in Filling Line of Lubricant Production Plant

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ABSTRACT

In the filling line of lubricant production plant of BP Castrol Thailand, pipeline cleaning processes, especially flushing process by using flushing oil, are performed to prevent unacceptable level of cross contamination. The flushing oil quantity used for each batch change must be optimized to maximize the efficiency of this plant since there are some formula changes of the products. Besides, accordingly to data between 2015, 5% of current product did not meet their specifications after flushing process. This led to re-blending and caused more operation cost. To prevent these problems occurring in the future, this project was done to optimize the flushing oil quantity for each flushing process and create standards using for filling line flushing. There are various types of batch change in this plant; therefore, representatives for each types of batch change were examined. Then, flushing process cycle and flushing oil quantity for each cycle were specified. After doing each flushing process cycle, flushed oil sample was collected for the product specification check. The standards were created based on the obtained data. The quantity of flushing oil for each flushing process was determined and performed in standards using for filling line flushing. 18% of flushing oil quantity is saving per year.

Keywords: Cross contamination, Lubricant, Filling line, Flushing process,

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Thanutchaporn Bhamarasuta

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Nomenclature

Latin letter

D	Kinematic viscosity deviation of formulated oil at 100°C (cSt)
M_P	Metal content in next product (ppm)
M_R	Metal content in oil residual (ppm)
W_F	Weight of flushing oil (kg)
W_P	Weight of next product which is to be filled (kg)
W_R	Weight of oil residual in filling line (kg)

Greek letter

μ	Absolute viscosity (cP)
η	Kinematic viscosity (cSt)
ρ	Density (kg/m^3)

Abbreviation

API	American Petroleum Institute (-)
ASTM	American Society for Testing and Materials (-)
BO	Base oil (-)
BP	British petroleum (-)
CCM	Cross Contamination Matrix (-)
CCS	Low temperature viscosity (cP)

FG	Finished good (-)
OEM	Original Equipment Manufacturer (-)
SAE	Society Automotive Engineers (-)

Chapter I
Introduction

1.1. Background

In lubricant production plant of BP Castrol Thailand, lubricant production consists of two sections: blending and filling sections. In the blending section, base oils are blended with additives in the blender tank and lubricant is obtained. Then, lubricant is transferred to the holding tank in the filling section. After that, it flows in the pipeline of the filling line to the filling machine where lubricant is filled into a package for each type, namely small pack filling, drum filling, and bulk filling. The lubricant in the package is also known as finished goods (FG). In the filling line, there are some oil residual of previous product remaining. When next product is filled without the proper pipeline cleaning process, the oil residual will contaminate with the next product. This contamination effects to the quality of the next product. This contamination between the residual and the next product is called cross contamination. Acceptable level of cross contamination is significant for each lubricant changing in the filling line of this plant. The level of acceptable cross contamination can be determined from cross contamination matrix (CCM). The cross contamination of product family group is applied in this matrix instead of cross contamination between each product since there are various types of products produced in this BP plant. The list of the family group of the previous product has presented in the column of CCM, while the list of the next product family group has illustrated in the row of CCM. Color shade in each cell represents the level of acceptable cross contamination. The acceptable level of cross contamination can be classified into two main cases, namely severe and general cases. Hence, before the next product filling starts, the proper pipeline cleaning process must be done to prevent of unacceptable level of cross contamination. General process of pipeline cleaning is divided into three steps. The first step is purging by pressure air at 2-5 bars to decrease the oil residual in the pipeline. In the second step (pigging), pigging ball is normally used for pipeline cleaning to remove the existing residual at the pipe wall. The last step of the pipeline cleaning is flushing by using flushing oil. Flushing oil can be classified into base oil and finished goods. After the flushing process, flushed oil obtained at the end of the pipeline. This flushed oil can be used as a raw material for blending of next production. Thus, it will not be considered as a waste.

From the filling line flushing process of BP plant, there are some formula changes of the products. In addition, accordingly to data between 2015, 5% of current product did not meet their specifications. This led to approximate 620,000 L of lubricant must be re-blended and it caused more operation cost (2.17 million baht is spent per year). Moreover, around 2,300 L of lubricant lost during the re-blending process and 9,200 baht lost per year. Therefore, it is vital that the quantity of flushing oil in each flushing process should be optimized in order to maximize the efficiency of this plant. BP Castrol Thailand concerns about these problems and wants to prevent these problems occurring in the future. This project was carried on to optimize the quantity of flushing oil in each flushing process and create standards used for filling line flushing process for being a working guideline and database for other standards of BP in other countries.

1.2. Objectives

1) To optimize flushing oil quantity applied in filling line flushing process.
2) To create standards used for filling line flushing process.

1.3. Scopes of study

1) Small pack filling and bulk filling are studied.
2) Study and analyze historical data of product filling from January, 2016 to September, 2016, to determine and solve problem.
3) Determine method to optimize quantity of flushing oil in each filling machine.
4) Create standards used for filling line flushing.

1.4. Expected outputs

The expected outputs of this project were:

1) Proper condition for filling line flushing process

2) Zero risk of occurring poor quality products after flushing process.
3) New standards using for filling line flushing process for being working guidelines and database for other standard specification for BP Castrol on other countries

Chapter II
Literature Review

2.1. Lubricants

The term of lubricant is generally defined as all of lubricating materials applied as fluid widely used in household, commercial, and industrial. There are various types of lubricant such as grease and lubricating (lube) oil. In general, majority of using lubricant is the lubricating oil since it is necessary for keeping equipment, especially in engine, operating for long period with an efficient manner. It is commonly applied to minimize friction between two surfaces in relative motion causing wear and heat in equipment e.g. engine and machinery.

2.1.1. Lubricant functions

A lubricant performance or requirement for the equipment maintenance should fulfill the following significant functions:

1) The frictional resistance reduction

The lubricant performance is dependent on viscosity of the oil which influences the ability of the oil to form lubricating film cover the equipment surfaces for friction loss reduction.

2) Contributing the thermal equilibrium

When the equipment works, heat is also generated. Using lubricant performs the thermal release by heat convection from the equipment to surrounding led to the machinery temperature decrease.

3) Removal of all injurious impurities

In modern engines, combustion in the engine leads to carbon deposit generation resulting in corrosion and mechanical wear. The lubricant gives the function of engine protection by cleaning the deposit and impurities from the metal surfaces and dispersing the impurities into the oils.

4) Protection of the engine against all wear types

Other from the impurities, steam and gas are normally generated from the fuel combustion, particularly in diesel fuel, and this leads to corrosion an oxidation in the lubricants. When the lubricants are mixed with water, emulsion is generated. This emulsion has a lower load carrying capacity than pure oil and lubricating oil failure followed by damage to the operating surface can result.

5) Protection of gas and oil leakages in engine

When the combustion is in the cylinder and piston of engine, pressure normally increases and resulting in gas and oil leakages. Using the lubricants decreases space between cylinder and piston to prevent the leakages.

2.1.2. Lubricant properties

Lubricants are formulated by blending base oils and additives to meet a series of performance specification. The specifications relate to the lube oil properties when it is new and also ensure that the oil continues to friction and chemical properties. The properties can be classified into physical and chemical properties.

2.1.2.1. Physical properties

The main physical properties are viscosity, viscosity index, low temperature property, and high temperature property.

1) Viscosity

Viscosity is a measurement of the internal fluid friction which is being deformed by either shear or tensile stress at a given temperature. Sometimes, it is also known as the thickness of oil which influences the ability of the oil to form a lubricating film to reduce friction loss. If the oil is too thin or low viscosity, the oil will not withstand the forces that form between moving parts causing wear and fouling of mechanical parts. Conversely, if the oil is too thick or high viscosity, it will not penetrate into the tiny operating between moving part.

Viscosity can be measured into absolute viscosity (μ) which is a measure of internal resistance in unit of centipoise (cP) or kinematic viscosity (υ) which is the ratio of - absolute viscosity to density - a quantity in which no force is involved in unit of centistoke (cSt). The kinematic viscosity is always applied in the lube oil viscosity measurement by using the standard method of ASTM D445. The relation between the absolute viscosity and kinematic viscosity is defined as follows:

$$\upsilon = \frac{\mu}{\rho} \times 10^3$$

Equation 2.1 The relation between kinematic viscosity and absolute viscosity

The quality and viscosity which is dependent on temperature are specified by the SAE in order to select the proper lubricant for using under temperature and pressure conditions of the engine. In the SAE standard, two series of viscosity grade are defined as a set of numbered grade and a set of winter-grade which is given a "W" designation.

The former is based on flow rate measurement at 100°C (212°F). The grade can be divided into six grades including SAE 10 through SAE 60, as shown in Table 2.1. The latter is intended for using at low temperature based on a maximum low temperature viscosity and a maximum borderline pumping temperature. The winter grade consists of SAE 0W through SAE 25W illustrated in Table 2.1.

From the both sets of viscosity grade, it can be defined as mono-grade which can be applied only in an acceptable option at constant temperature. As a result of this problem, chemical additives (viscosity index improver) were added for blending with the oils to solve the problem and improve temperature specification of lubricant, and thus this mixed oil became known as multi-grade for use over a wider temperature range than mono-grade oil, as shown in Figure 2.1.

2) Viscosity/temperature relationships-viscosity index

The most frequently used method for comparing in the variation of viscosity with temperature between different oils, known as viscosity index (VI). VI is generally determined by measurement of the KV at more than one temperature (usually measurement at 40°C and 100°C).

Table 2.1 SAE J300 – Automotive Engine Oil Classifications[5]

SAE Viscosity Grade	Low temperature viscosity		High temperature viscosity	
	Cranking: cP @ °C, max. (ASTM D5293)	Pumping: Max. cP with no yield stress @ °C (ASTM D4648)	Kinematic: cSt @100°C (ASTM D445)	High shear: cP @150°C
0W	6,200 @ -35	60,000 @ -40	3.8 minimum	-
5W	6,600 @ -30	60,000 @ -35	3.8 minimum	-
10W	7,000 @ -25	60,000 @ -30	4.1 minimum	-
15W	7,000 @ -20	60,000 @ -25	5.6 minimum	-
20W	9,500 @ -15	60,000 @ -20	5.6 minimum	-
25W	13,000 @ -10	60,000 @ -15	9.3 minimum	-
20	-	-	5.6 – 9.3	2.6
30	-	-	9.3 – 12.5	2.9
40	-	-	12.5 – 16.3	• 2.9 (for 0W-40, 5W-40, and 10W-40 grade • 3.7 (for all grade)
50	-	-	16.3 – 21.9	3.7
60	-	-	21.9 – 26.1	3.7

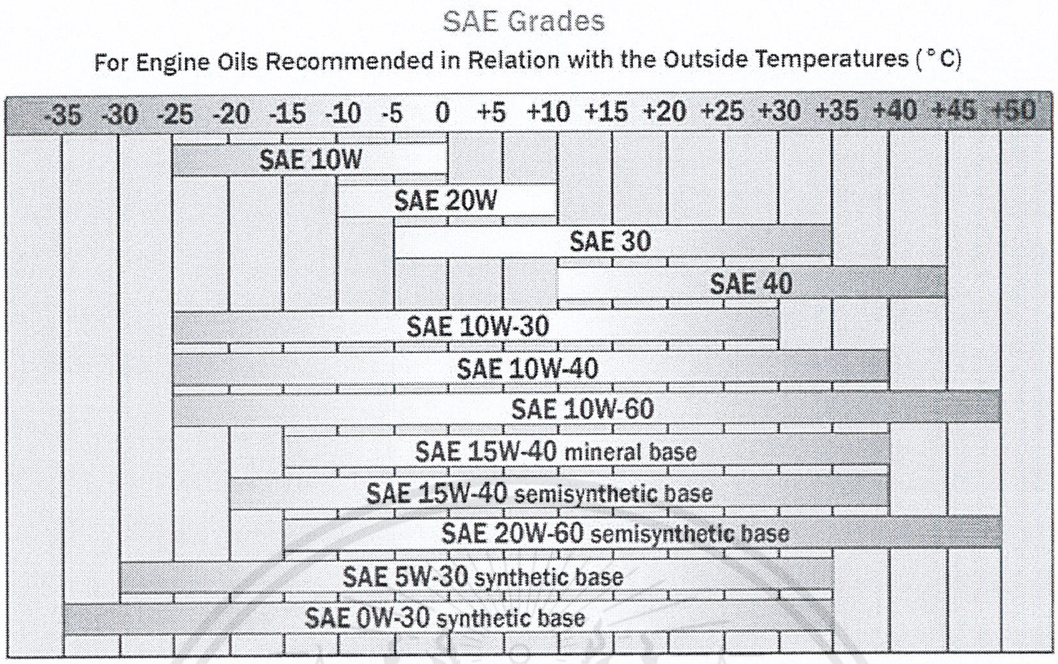

Figure 2.1 A general reference for viscosity selection based on ambient temperatures.[4]

3) Low temperature property

When a sample of oil is cooled, its viscosity increases in a predictable manner until wax crystals start to form. The matrix of wax crystals becomes sufficiently dense with further cooling to cause an apparent solidification of the oil. Hence, pour point which is one of the main properties should be tested. Pour point is the lowest temperature at which the sample of the sample of oil can make to flow by gravity alone.

4) High temperature property

The high temperature properties, particularly in flash point, of oil are governed by distillation or boiling range characteristics of the oil. Flash point is important for oil from a safety point of view because it is the lowest temperature at which auto-ignition of the vapor occur above the heated oil sample. Different methods are used, ASTM D 92, D93, and are essential to know which equipment has been used when comparing results.

2.1.2.2. Chemical property

One of the most important chemical properties is oxidation stability since oxidation causes the chemical reaction between oils and oxygen which form organic acid resulting in corrosion. Therefore, it's essential that the lubricating oil; when exposed to high temperature (above 71°C or 160°F); doesn't contribute to the forming of deposits even after a long period of continuous engine running. So, the lubricant resistance to the oxidative depends mainly on the nature of the lubricant and the presence of anti-oxidant additives.

2.1.3. Lubricant composition

The modern lubricants are almost formulated from a mixture of two or more ingredients which most of them are base oils and additives.

2.1.3.1. Base oil

Approximately 90% of the lubricant is base oil or base stock. Base oil is the vital portion of the finished lube oil product since it results in product performance, especially viscosity. In some case of formulating lube oil, two or more base oil types are normally formulated to modify the product characteristics.

Base stocks are made from the viscous portion of the petroleum, taking into refinery process for crude oil distillation, or using synthetic hydrocarbon and ester technologies. It can be classified into five grades, as shown in Table 2.2, in accordance with the API base stock category standard by using base oil sources and characteristics as criterion.

Table 2.2 API base stock categories [3]

Category	Amount (%)		Viscosity index, VI
	Saturates	Sulfur	
API Group I (Solvent-refined)	< 90	> 0.03	80 – 120
API Group II (hydro-processed)	≥ 90	≤ 0.03	80 – 120
API Group III (hydro-cracked)	≥ 90	≤ 0.03	≥ 120
API Group IV is polyalphaolefins (PAO)			
API Group V is for ester and other base stocks not included in group I - IV			

The first three groups are derived from crude oil by distillation and other modifications such as solvent extraction, hydrocracking, hydro dewaxing, and hydro treating. The distillated crude oil is also known as mineral base oils or conventional base stocks. In general, hydrocarbon which carbon content ranging from 83% to 87% and hydrogen content from 11% to 14% predominate in all crude oil and can be further subdivided:

1) Paraffins

Paraffins or alkanes are hydrocarbon with saturated linear illustrated in Figure 2.2 (a) or branched chain structure presented in Figure 2.2 (b). Base oils including paraffins are called paraffinic base stocks which the properties are good viscosity or temperature characteristic and good oxidation resistance.

2) Alicyclics or naphthenes (as shown in Figure 2.2 (c))

There are saturated cyclic structures based on five- or six-membered ring. Due to the structure, the characteristics of naphthenic base oils are low pour point and therefore, their temperature characteristic are inferior to the paraffinics

3) Aromatics (as given in Figure 2.2 (d))

There are cyclic structures with conjugated double bonds, based on the six-membered benzene ring.

The mineral oils are the most commonly used lubricants throughout industry for applications where temperature requirement are moderated.

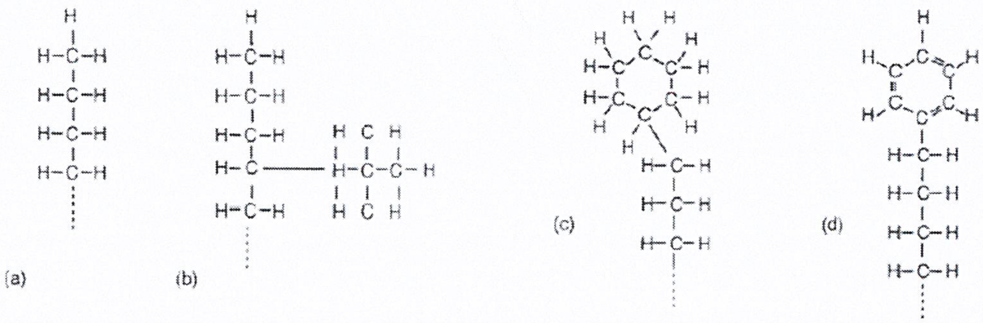

Figure 2.2 Chamical structure of lubricating oil

(a) linear paraffin, (b) branch paraffin, (c) naphthenic component, and (d) aromatic with paraffin side chain.[3]

In the API base stock group IV, base oils are synthetic which are derived from the catalytic polymerization of olefins. The synthetic base stocks are produced to modify the performance of mineral base oils, especially in temperature characteristics. Polyalphaolefin (PAO) is one of the generally used synthetics oil examples which are produced from free radical processes and catalytic processes. The API base stock group V, on the other hand, is for all other base oils not included in group I-IV. Most of the base oils are ester.

Other from base oil source consideration, the base stock characterization including the saturate amount, sulfur levels, and viscosity index, as mentioned above in topic of lubricating oil properties) is important for categorized the API base oil standard, particularly in group I, II, and III classification. Saturates are type of molecule found in base oils. The higher the number of saturates results in the higher molecular bond strength of the oils and therefore better resistance to oxidation and viscosity loss. The sulfur levels present in the oil can have some beneficial, as well as some detrimental, effect on operating machinery. Sulfur is an excellent boundary agent, which can effectively operate under extreme conditions of pressure and temperature. However, it is very corrosive. Hence, the lower the sulfur content, the better the purity and thus the less the corrosive and oxidation potential that exist. VI is an indication of the rate of viscosity change against temperature, and the higher the VI, the better.

2.1.3.2. Additives

Lubricating oils commonly change the characteristic as a result of viscosity change, oxidation, entering of impurity and dirt, etc. Due to this problem, numerous additives consisting of various organometallic substances are selected and properly blended to achieve a delicate balance in the finished product performance.

Additives can be classified into 13 types such as detergent, rust inhibitor, foam inhibitor, viscosity index improver, emulsifier, etc. In summary, it can be classified into four main function groups:

1) Cleaner additives are applied to prevent and suppress deposition of generated byproduct due to high temperature operation of machines.

2) Anti-oxidant additives are generally applied to react with radicals and peroxides to suppress varnish and sludge formation resulting from oxidation.

3) Anti-corrosion additives neutralize corrosive oxidation products resulting from the breakdown of lubricating oils.

4) Solid additives are used as thin film or powder to reduce friction and wear.

2.2. Lubricant production of BP Castrol Thailand

The process in the lubricant production of BP Castrol Thailand consists of two sections: blending and filling sections.

2.2.1. Blending section

Blending is a procedure of mixing of mixing raw material between base oils and additives to produce lubricant. The blending section is divided into manual and automatic blending. The former is controlled by operators. In the latter, auto batch blending program is used for the blending controller.

There are four main steps of the blending process.

1) The first step is a mixing of additives. Additives are mixed in the mixing tank at 60°C for approximate 15 minute before the blending process starts since there are some additives which is too viscous to blend with base oil such as polymer.

2) In the second step, the mixed additives are transferred to the blending tank. Then, the mixed additives are blended with base oils in the blending tank for at 60°C an hour.

3) Lubricant is obtained and some lubricant is taken to check the quality of the lubricant.

4) The last step of the blending section is a transfer of the lubricant which meets its specification to the holding tank in the filling section.

2.2.2. Filling section

Filling is a procedure of lubricant filling into a container. The procedure is as following:

1) First, filling machine is prepared by operators. Container size, the quantity of the lubricant for each type of containers, and filling machine system are set.

2) Second, the lubricant which is in the holding tank flows in the pipeline of the filling line to the filling machine.

3) Lubricant is filled at the filling machine into a container for each type such as small pack, drum, or bulk truck. The lubricant in the container is called finished goods.

4) Some lubricant is taken from filling machine to check the quality of the product after filling process.

5) The containers with finished goods are sent to storage.

2.2.3. Product specification check

Main product specification consists of product color, kinematic viscosity, low temperature viscosity (in case of winter-grade viscosity of lubricant), and metal content.

2.2.3.1. Product color

Approximately 95% of products in BP Castrol-SS plant are natural color (amber or brown). However, color is added in some oil groups to identify product type, for example, red color is added to perform automatic gear and marine oil or green color is added to identify OEM oil (lubricating oil that are produced especially for car industrial e.g. Ford, Honda, etc.)

Color is the most important specification. If the filled product color changes, it means finished goods are off-spec.

2.2.3.2. Kinematic viscosity

Kinematic viscosity of finished goods should be in accordance with the SAE standard, as shown in Table 2.1. Product is examined at 100°C.

For filled product, ASTM D445-15a is used for the kinematic viscosity test. Pass kinematic viscosity of the product must be following deviation of kinematic viscosity test of blending. The calculation is given in Equation 2.2.

$$D = \upsilon_{blending} \times 1.38\%$$

Equation 2.2 Kinematic viscosity deviation of filled product

The kinematic viscosity of filled product must be in range of deviation to reach the quality pass, as following:

$$\upsilon_{\max} = \upsilon_{blending} + D \quad \text{---------------------------- (a.)}$$

$$\upsilon_{\min} = \upsilon_{blending} - D \quad \text{---------------------------- (b.)}$$

Equation 2.3 (a.) the maximum kinematic viscosity of filled product, (b.) the minimum kinematic viscosity of filled product

2.2.3.3. Low temperature viscosity

Low temperature viscosity is measured by cold-cracking simulator (CCS) to simulate the action of the started motor on an engine. The maximum low temperature viscosity is referred to ASTM D2602. This test is significant since the mechanical parts can overcome only so much resistance and still produce adequate cracking speed at low temperature. For example, SAE 15W upper limit viscosity is 7,000 cP, as illustrated in Table 2.1.

2.2.3.4. Metal content

Metal is from additives which consist of various organometallic substances. Different product formula means different ratio of metal in the lubricant. Thus, it is important that the metal content in the lube oil must be controlled to be in the range of metal amount of each product formula.

2.3. Pipeline cleaning

In the filling line, there are some oil residual of the previous product remaining. When the next product is filled without the proper pipeline cleaning, the oil residual will contaminate with the next product. This contamination effects to the quality of the next product. As a result of the next product quality change from the contamination, pipeline cleaning is done to prevent the contamination between the oil residual and the next product.

General process of pipeline cleaning consists of three steps: purging, pigging, and flushing processes.

2.3.1. Purging

Purging is widely used in petrochemical industrial by using pressure air at 2-5 bars to decrease the oil residual remaining in the pipeline.

2.3.2. Pigging

Pigging process refers to the practice of using devices known as "pigging ball", as shown in Figure 2.3. Pigging ball is used in order to clean the pipes to avoid cross-contamination, and to empty the pipes into the product tanks (or sometimes to send a component back to its tank). Usually pigging is done at the beginning and at the end of each batch. Pigging ball normally consists of a steel body with rubber or plastic caps attached to seal against the inside of the pipeline and to allow pressure to move the pig along the pipeline.

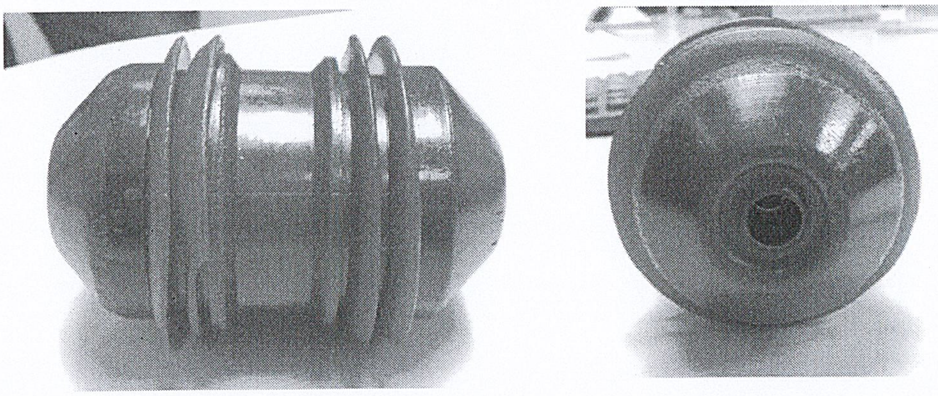

Figure 2.3 Pigging ball

Equipment is required to introduce the pig into the pipeline and to retrieve the pig at the end of the segment being pigged. A launcher is required at the upstream of the section and a receiver at the down-stream end. The distance between these pig "traps" depends on service, location of pump or compressor stations, operating procedures and the material used in the pig.

Nevertheless, purging and pigging cannot absolutely empty the production system. Hence, another cleaning procedure, flushing, is necessary for the lubricant manufacture.

2.3.3. Flushing process

The lubricant in some product family groups are incompatibility, non-miscibility, or low acceptable contamination level with others family groups. Blending and filling systems should be ideally separated to avoid cross-contamination. However, the plant space is limited to install the ideal separation systems. Furthermore, purging and pigging do not absolutely clean contamination from the previous product. Therefore, flushing procedure is necessary for the production to maintain product quality in accordance with BP Castrol and international standard. In this report, only filling line flushing is focused on and discussed.

Flushing is a cleaning procedure using flushing oil to remove oil residual in the filling line. The flushing can be categorized into BO flushing and FG flushing. In the former, proper base oil must be chosen to remove contamination and modify product specification, especially kinematic viscosity. The appropriate base oil for BO flushing is dependent on main base oil in product to be filled. In particular, if the main base oil of the next product is fully-synthetic, the same type of fully-synthetic oil must be used as flushed oil to maintain maximum low temperature viscosity since maximum low temperature viscosity of fully-synthetic oil is lower than mineral oil. If it is contaminated with mineral oil, the following product maximum low temperature viscosity will be off-spec. other from this condition, most of proper flushed oil should be base oil that is same the main base oil in previous product. The latter flushing is a procedure using finished goods.

The flushing oil mixes with oil residual and removes oil residual. The mixing oil between flushing oil and oil residual is also known as flushed oil. Flushed oil can be re-blended to produce same previous product in next batch.

Chapter III
Research Methodology

Lubricant products in BP Castrol (Thailand) Limited is produced from base oils blending with additives. Most metal which was found in additives is M1, M2, M3, and M4. These metals are important for product family group classification. Besides, these are criterion for product specification check.

Products in this plant can be classified into various regimes. Product family definitions have remained broadly the same but sub-family definitions have been revised to reflect the current range of product types within a family. The main criterions are type of equipment which the lube oils are used and organometallic substance in the oils.

The former can be divided into automotive oils, motorcycle oils, gear oils, marine oils, industrial oils, hydraulic oils, and neat metalworking oils. In the latter, M1 free or containing in the oils are considered for categorization. Therefore, the products can be summarized into 10 family groups as given in Table 3.1.

Table 3.1 Family group of lubricant product

Family group	Explanation of Family Group
01	Straight Base Oils-Additive Free (<10 ppm metals)
02	M1 free Industrial oils
03	M1 containing Industrial oils
04	M1 containing Engine Oils
05	M1 free engine oils
06	Gear oils
07	ATF
08	Neat metalworking oils
09	Oils Containing Fats
10	2-stroke oils

When batch change from one family group to another one results in cross contamination causing product quality change, pipeline cleaning is necessary to maintain the product specification. Pipeline cleaning can be considered from CCM, as shown in Figure 3.1.

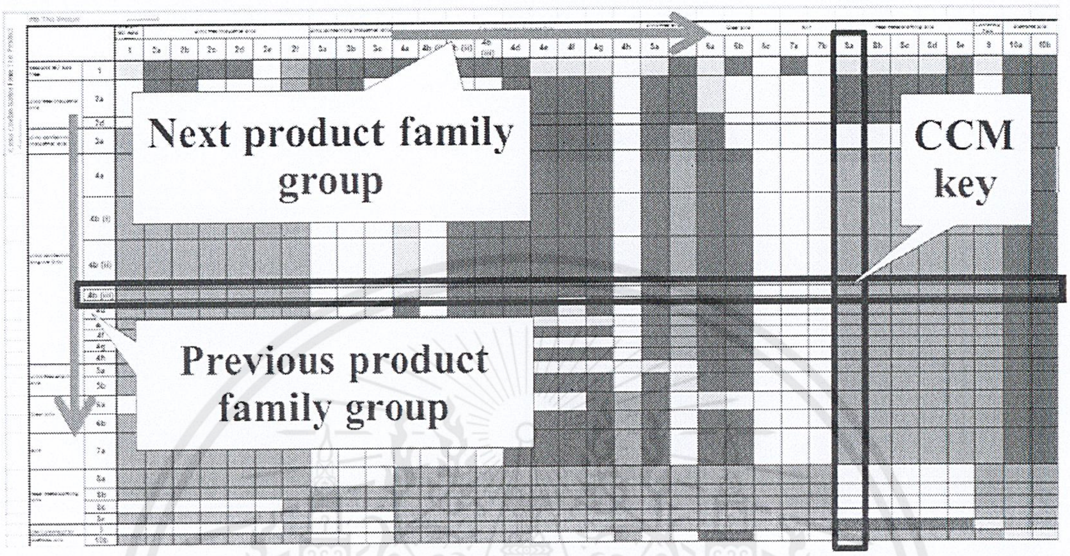

Figure 3.1 CCM

(Work instruction of BP Castrol (Thailand) Limited)

The matrix provides CCM key which is the information on the allowable level of carry-on from one product into the following product in manufacture. Each color represents a different level of allowable cross contamination as given in Table 3.2. From, CCM key which is red and yellow is in severe case; therefore, BO flushing is necessary, especially in product incompatibility case. In case of 0.1-0.2% acceptable cross contamination, BO flushing is vital for the next products which main base oil is fully-synthetic oil, as mentioned in 2.3.3. Flushing process.

Table 3.2 CCM key explanations

(Work instruction of BP Castrol (Thailand) Limited)

Case	CCM key	Cross contamination level
Severe	Red	0
	Yellow	0.1-0.2%
General	Purple	0.5%
	Blue	1.0%
	Green	5.0%

To optimize flushing oil applied in filling line and create new standards using for filling line flushing, this project was done as following procedures:

3.1. Selection of representative for each type of batch change

3.1.1. Representative selection

In BP Castrol (Thailand) Limited, many product formula are produced in each family group. Furthermore, many product family groups are filled in each filling machine. Hence, it is vital that some batch changes should be selected for this project by using criterion.

The criterion consists of kinematic viscosity change ($\eta_{previous} \geq 3\eta_{next}$), severe group of the level of acceptable cross contamination, and metal content change. In case of metal content change, the suitable product should be metal removal case or vastly different change of metal content case.

3.1.2. Representatives

From the criterion in Error! Reference source not found., 13 proper samples are selected. It can be classified as given in Table 3.3. Reasons of choosing these samples are represented in Table 3.4.

Table 3.3 Number of selected samples in each filling line

Problem case	Filling machine	All of number of batch change	Number of selected sample
I. Product formula change	Small packing 1	91	4
II.A. 5.00% number of filled batch off-spec	Gear bulk	16	1
II.B. High risk	Small packing 2	25	1
	Small packing 3	441	4
	Engine bulk	25	3

Table 3.4 Reasons of choosing samples

Case	Filling machine	Batch change		Selection reasons		
		From	To	υ change	Severe CCM key	Metal content change
I	Small packing 1	Family 04a	Family 04b(i)	-	-	M3 removal
		Family 04a	Family 04b(ii)	-	-	M1 reduction
		Family 04a	Family 04a	-	-	M3 removal
		Family 04b(ii)	Family 04a	-	-	M3 removal
II	Gear bulk	Family 06b-SAE 60	Family 06b-SAE 10W	From 24 cSt to 4 cSt	-	-
	Small packing 2	Family 10b	Family 04b(iii)	-	0.00%	-
	Small packing 3	Family 04b(i)	Family 04b(i)	-	0.10%	-
		Family 04b(ii)	Family 04b(i)	-	0.10%	M1 reduction

		Family 04b(i)	Family 04a	-	-	M2 reduction + M3 removal
	Engine bulk	Family 04b(i)	Family 04b(i)	-	0.10%	M3 removal
		Family 04b(ii)	Family 04b(i)	-	0.10%	-
		Family 04b(i)	Family 04b(ii)	-	-	M3 increase

3.1.3. Selection of the appropriate flushing process for each representative

In filling line flushing, flushing process can be classified into two groups:

1) BO flushing process following FG flushing process
2) Using only FG flushing

It is significant that proper flushing process is chosen for each batch change. The flushing process choosing can be considered as following flow chart in Figure 3.2.

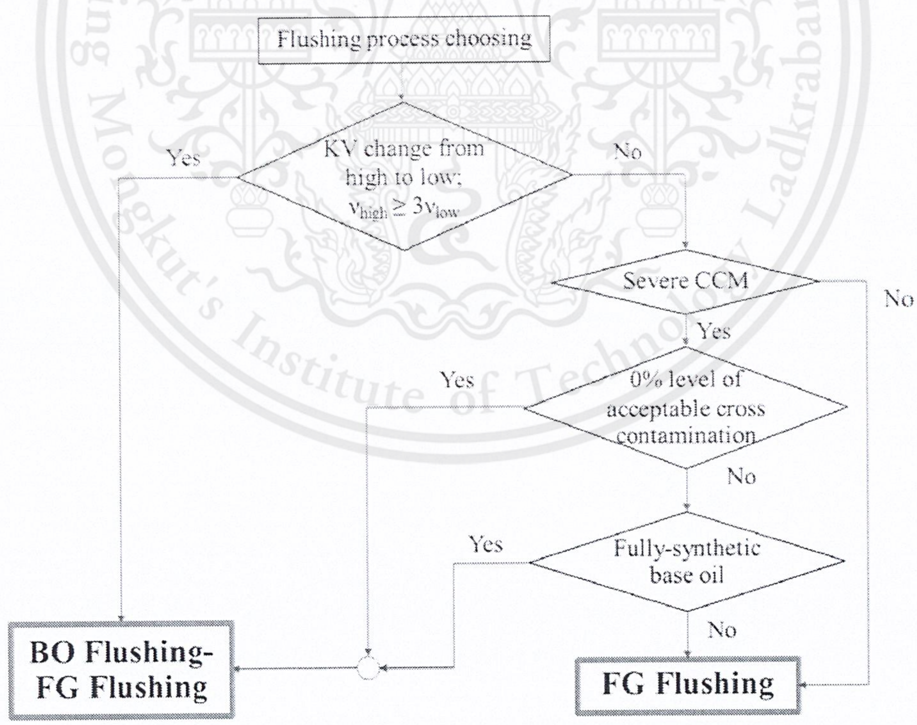

Figure 3.2 Flowchart of selection of the appropriate flushing process for each representative

3.2. Perform experiment.

3.2.1. Experimental

3.2.1.1. Using BO flushing process following with FG Flushing process

The procedure is as following:

1) Specify flushing cycles for BO flushing and FG flushing, then specify flushing oil quantity for each cycle.
2) Perform the first cycle of BO flushing process, as mentioned before in topic 2.3.3. Flushing process.
3) Take some flushed oil from filling head of filling machine after flushing cycle finishes.
4) Do step 2 and 3 until all of BO flushing cycles have already been done.
5) Perform the first cycle of FG flushing.
6) Take some flushed oil from filling head of filling machine after flushing cycle finishes.
7) Do step 2 and 3 until all of FG flushing cycles have already been done.
8) Samples are sent to laboratory for product specification test.

3.2.1.2. Using only FG Flushing process

The procedure is similar to procedure of using BO flushing process following with FG Flushing process. Only step 1, 5, 6, 7, and 8 are done.

3.2.2. Criterion for Pass Flushing Consideration

After flushing process finishes in each flushing cycle, some flushed oil are taken from filling head to test product specification as following in Table 3.5. The optimizing flushing oil quantity can be determined when all of flushed oil properties pass.

Table 3.5 Criterion for Pass Flushing Consideration

<table>
<tr><th>Product specification</th><th>BO flushing</th><th>FG flushing</th></tr>
<tr><td>Color</td><td>Following the next product specification</td><td rowspan="4">Following the next product specification</td></tr>
<tr><td>Kinematic viscosity</td><td>Not test</td></tr>
<tr><td>Low temperature viscosity</td><td>Not test</td></tr>
<tr><td>Metal content</td><td>%metal < M_{STD}%</td></tr>
</table>

3.2.2.1. Product color

The pass flushed oil sample color must be same as the following product in case of FG flushing process and must be similar to base oil in case of BO flushing process. If the sample color is not same as flushing oil, it means this flushing fails to remove the previous oil and other contaminations.

3.2.2.2. Kinematic viscosity

Kinematic viscosity of flushed oil sample should be in in range of kinematic viscosity deviation. The deviation can be calculated by using Equation 2.2 and Equation 2.3.

3.2.2.3. Low temperature viscosity

Low temperature viscosity of pass flushed oil sample must be less than the maximum low temperature viscosity of the next product, as shown in Table 2.1.

Viscosity test is not necessary for BO flushing process although this flushing process is applied for adjust viscosity. The reason is FG flushing process must be done after this process and FG flushing will adjust the viscosity of product into range of product specification.

3.2.2.4. Metal content

In BO flushing, only color and metal content are examined to remove or vastly reduce contamination in filling line. In particular, percentage of metal contamination in BO flushed oil must be less than M_{STD} % in accordance with

BP Castrol standard to ensure that product specification after doing FG flushing does not off-spec. It can be calculated by Equation 3.1 and Equation 3.2.

$$W_R = \frac{\%M_R \times W_F}{\%M_F}$$

Equation 3.1 Weight of previous product in filling system calculation

$$\%\text{contamination} = \frac{W_R}{W_P} \times 100\%$$

Equation 3.2 Percentage of contamination in next batch at full product volume calculation

On the other hand, metal content of flushed oil after doing FG flushing process must be following the BP product formula.

3.3. Creation of the standards used for filling line flushing.

Standards used for flushing in filling line are working guideline for using proper flushing oil quantity in filling line. The standard is shown in a matrix between previous product and next product to present the proper flushing types and flushing oil quantity for each batch change in each filling machine.

The procedure of creating the new standards is as following:

1) The matrixes for each filling machine were designed and created.
    a. Matrix column presents previous product family group.
    b. Matrix row indicated next product family group.
    c. The color shade in each cell represents the level of acceptable cross contamination.
2) The proper flushing oil quantity of the other batch changes can be determined by using results of selected samples. The flowchart in Figure 3.3 illustrate concept of proper flushing oil quantity consideration.

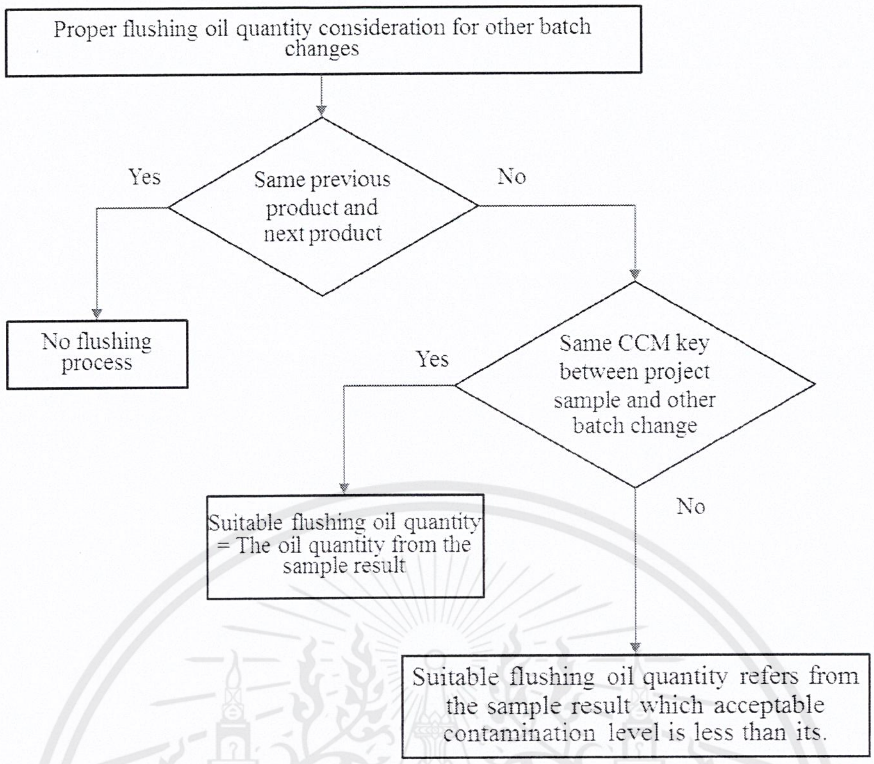

Figure 3.3 Concept of proper flushing oil quantity consideration

3.5. Evaluation of the profit from doing this project

Evaluation of flushing oil quantity optimization in filling line is to compare the results of the project with the current flushing to determine the flushing oil quantity saving. In addition, flushing time saving is determined since flushing time is dependent on flushing oil quantity in that 15 minute is used for flushing of 200 L of flushing oil.

Chapter IV
Results and Discussion

4.1. Case I. Product formula change

In this case, the lubricant is filled into a package at the small packing 1 only. The results are as following:

4.1.1. Small packing 1

4.1.1.1. The 1st sample: batch change from product family 04a to family 04b (i)

This sample is in group of 0.1-0.2% acceptable contamination level. Main base oil composition of the next product is not fully-synthetic. Hence, only FG flushing process was used in this sample. FG flushing process had carried out into three cycles by using 200 L of finished goods for each cycle.

From observation, flushed oil color passed within the determined color of the next product at the first cycle.

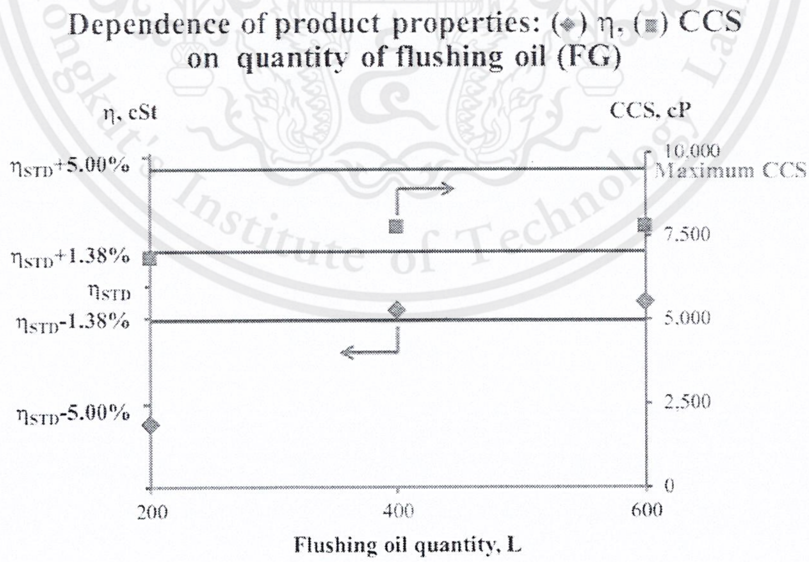

Figure 4.1 The variation of η and CCS on the quantity of flushing oil in the 1st sample of small packing 1

Figure 4.1 represents the variation of η and CCS on the quantity of the flushing oil. Red axis indicates the η of the flushed oil sample, while green axis indicates the CCS of the flushed oil. The determined condition of η is the η must be in the deviation range of η_{STD}. For CCS, the viscosity must be lower than the maximum CCS at 9,500 cP. From Figure 4.1, the CCS of all flushed oil samples was lower than the maximum CCS. The η of flushed oil sample met the deviation range of η when 400 L of flushing oil is used.

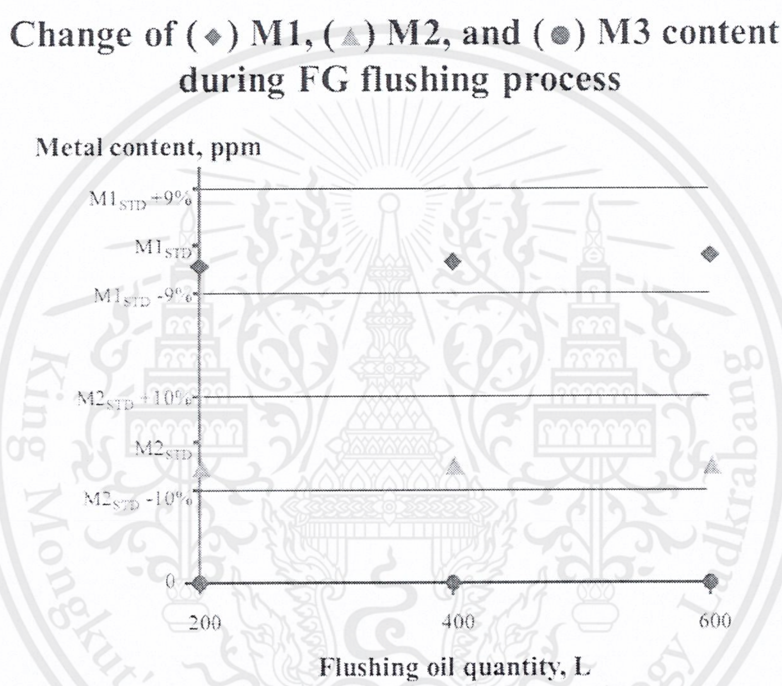

Figure 4.2 Change of M1, M2, and M3 contents during FG flushing process in the 1st sample of small packing 1

Figure 4.2 illustrates change of metal content during FG flushing process. Metal content must be in acceptable range of metal content standard. Metal M1 and M2 content were in range of $M1_{STD}$ deviation, Metal $M2_{STD}$ deviation respectively. Metal M3 must have been eliminated. From this graph, metal M3 in all samples was removed.

To optimize the quantity of flushing oil for this flushing process and maximize the efficiency of this plant, 400 L of finished goods is the proper quantity of flushing oil used for FG flushing process since all of the product specification met their determined conditions.

4.1.1.2. The 2nd sample: batch change from product family 04a to family 04b(ii)

Metal M1 content decreases around 9% from the previous product. The acceptable level of this batch change is 0.5%. Hence, only FG flushing process is used in this sample. FG flushing process had carried out into three cycles by using 200 L of finished goods for each cycle.

From observation, flushed oil color passed within the determined color of the next product at the first cycle.

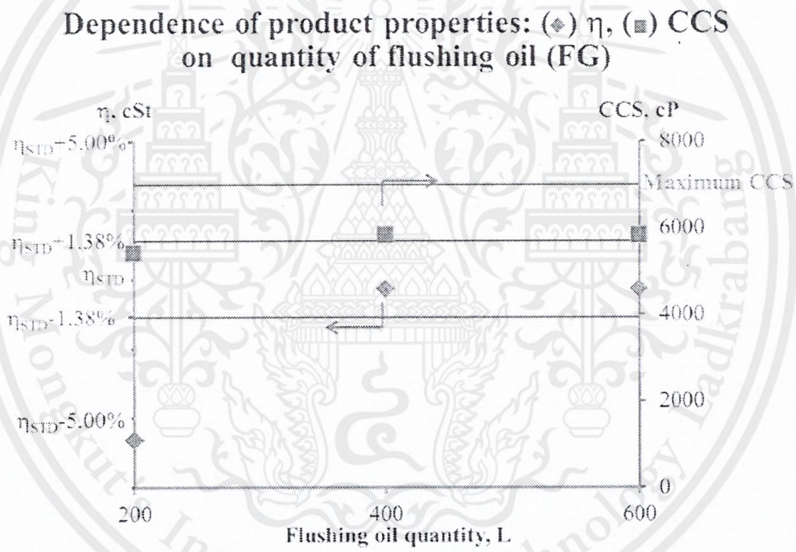

Figure 4.3 The variation of η and CCS on the quantity of flushing oil in the 2nd sample of small packing 1

Figure 4.3 represents the variation of η and CCS on the quantity of the flushing oil of the 2nd sample in the case I. The determined condition of η is the η must be in the deviation range of η_{STD}. The η of flushed oil sample met the deviation range of η when 400 L of flushing oil is used. For CCS, the viscosity must be lower than the maximum CCS at 7,000 cP. All samples passed within the determined condition.

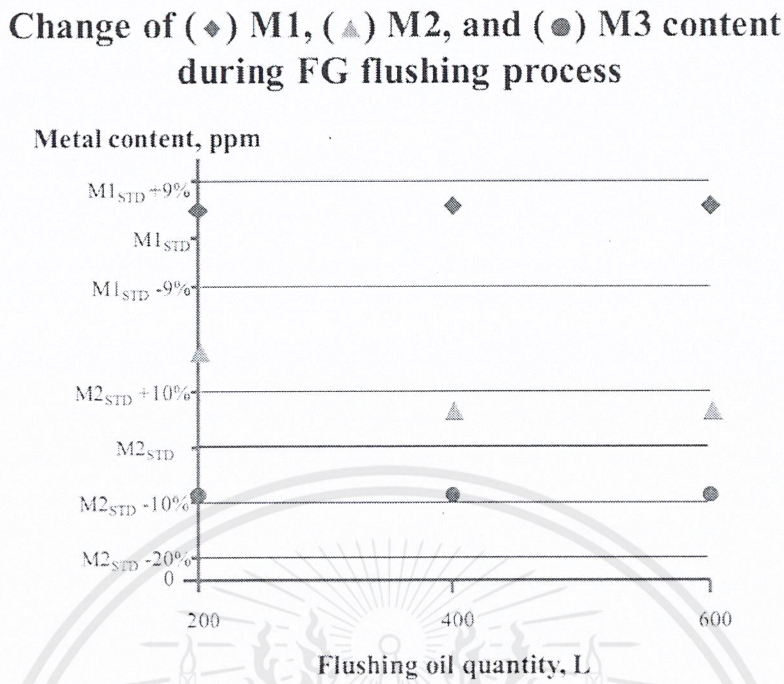

Figure 4.4 Change of M1, M2, and M3 contents during FG flushing process in the 2nd sample of small packing 1

Figure 4.4 illustrates change of metal content during FG flushing process of the 2nd sample in small packing 1. Metal content must be in acceptable range of metal content standard. Metal M1 were in range of $M1_{STD}$ deviation. Metal M2 must be in the deviation range of $M2_{STD}$ between $M2_{STD} \pm 10\%$, while metal M3 must be in the acceptable range between $M2_{STD} - 20\%$ to $M2_{STD}$. From Figure 4.4, Metal M2 content met the specification when 400 L of flushing oil was used. In metal M3, on the other hand, all samples passed within the acceptable range.

To optimize the quantity of flushing oil for this flushing process and maximize the efficiency of this plant, 400 L of finished goods is the proper quantity of flushing oil used for FG flushing process since all of the product specification met their determined conditions.

4.1.1.3. The 3rd sample: batch change from product family 04a to family 04a

In this batch change, metal M3 must be eliminated by using FG flushing process. FG flushing is separated into three flushing cycles and 100 L of flushing oil is used in each cycle.

When using only 100 L of flushing oil, product color met the color of the next product.

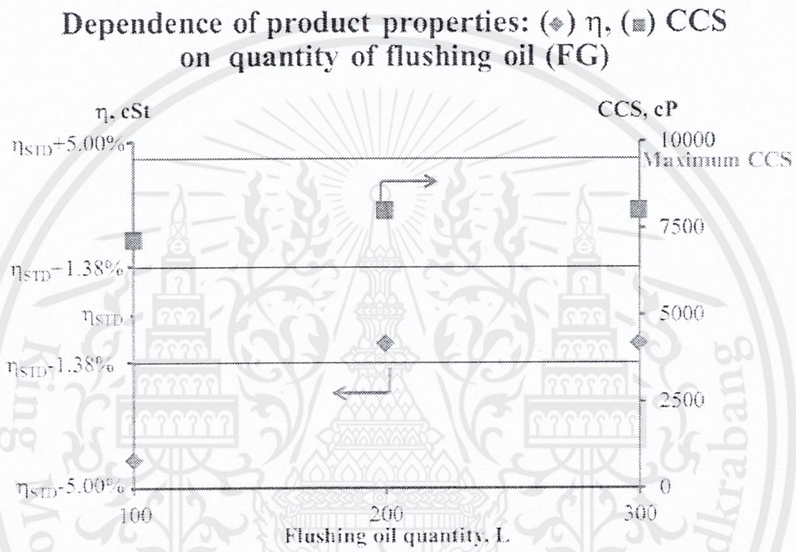

Figure 4.5 The variation of η and CCS on the quantity of flushing oil in the 3rd sample of small packing 1

Figure 4.5 shows the variation of η and CCS on the quantity of the flushing oil of the 3rd sample in the case I. The η of flushed oil sample met the deviation range of η when 200 L of flushing oil is used. For CCS, all samples passed within the determined condition.

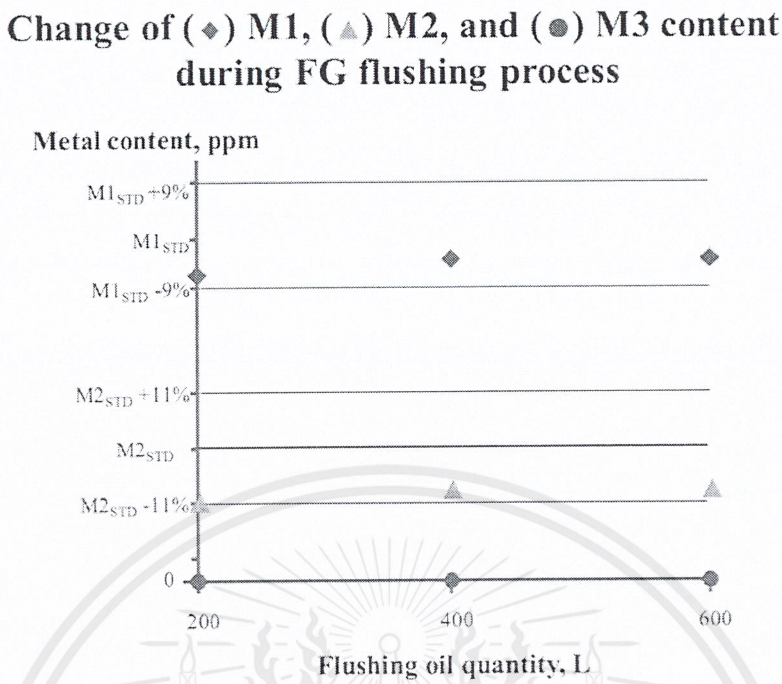

Figure 4.6 Change of M1, M2, and M3 contents during FG flushing process in the 3rd sample of small packing 1

Figure 4.6 indicates change of metal content during FG flushing process. Metal content must be in acceptable range of metal content standard. Metal M1 was in range of $M1_{STD}$ deviation, while Metal M2 is in the range of $M2_{STD}$ deviation at using 200 L of finished goods. Metal M3 must have been eliminated. From this graph, metal M3 in all samples was removed.

To optimize the quantity of flushing oil for this flushing process and maximize the efficiency of this plant, 200 L of finished goods is the proper quantity of flushing oil used for FG flushing process to meet the specifications of the next product.

4.1.1.4. The 4th sample: batch change from product family 04b(ii) to family 04a

This batch change is not in group of severe case; however metal M3 must be eliminated by using FG flushing process. FG flushing is separated into three flushing cycles. 100 L of flushing oil is used in the first flushing cycle, while 50 L of flushing oil is applied in the other cycles.

In this sample, only sample after using 200 L of flushing oil is examined since color of flushed oil sample in the first and second samples does not pass. It can conclude that the proper flushing oil quantity for this case is 200 L.

4.1.1.5. New standard using for flushing in small packing 1

Into This Product ------------>

Cross Contamination From This Product		Zinc containing Engine Oils		
		04a	04b(i)	04b(ii)
Zinc containing Engine Oils	04a	***3rd FG 200 L	***1st FG 400 L	***2nd FG 400 L
	04b(i)	FG 200 L	Same product (No flushing)	FG 400 L
	04b(ii)	***4th FG 200 L	FG 400 L	FG 400 L

Figure 4.7 The standard used for flushing in small packing 1

After the experiments were performed for the case of product formula change, standard used in small packing 1 has been created based on the results from representative batch change.

In the column, the list of previous product family group has presented and, in the row, the list of next product FG has presented. The color shade in each cell represents the level of acceptable cross contamination.

The symbol of "***" indicates the example shown before.

4.2. Case II. Current product

Some current products in this BP plant have the high risk which the product do not meet their specification after flushing process. The batch changes occurring in small packing 2, small packing 3, gear bulk, and engine bulk must be optimized in order to maximize the efficiency of this plant. The results are as following:

4.2.1. Small packing 2

Batch change from product family 10b to product family 04b (iii) represented severe cross contamination case (prohibited cross contamination). In this case, BO flushing process is necessary to eliminate oil residual.

4.2.1.1. Results

1) Base oil flushing process

BO flushing process had carried out into three cycles by using 200 L of finished goods for each cycle.

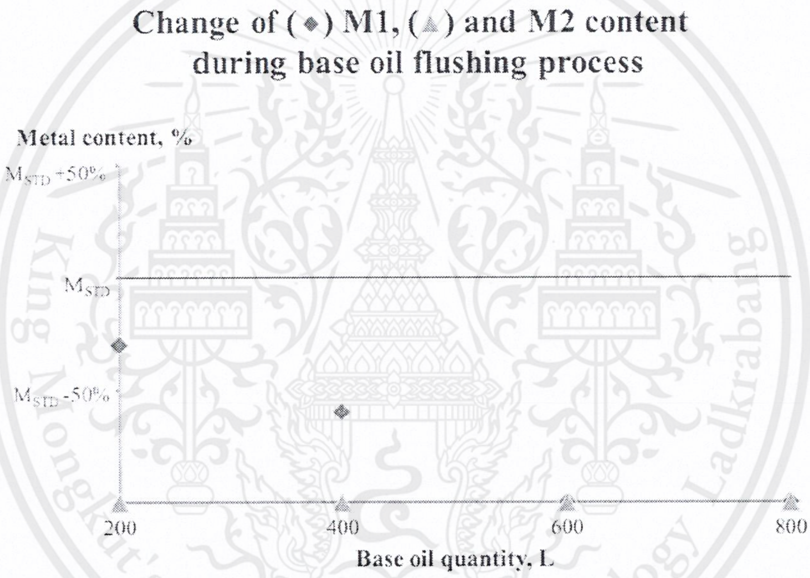

Figure 4.8 Change of metal content during BO flushing process in small packing 2

Figure 4.8 presented that both metal M1 and M2 contents were lower than $\%M_{STD}$ at the first cycle. Metal M2 is eliminated from BO flushing process. Despite of passed specification of metal content at 200 L of flushing oil, color of flushed oil failed. From the oil appearance observation, 600 L of flushing oil is proper to clean the oil residual color.

2) FG flushing process

From Figure 4.8, all of metal content is less than %contamination limit of BP; however, the metal contents are not in range of product formula. Hence, FG flushing process is important to adjust metal content to be suitable range. Three flushing cycles are tested and 200 L of finished goods is used for each cycle.

From observation, flushed oil color passed within the determined color of the next product at the first cycle.

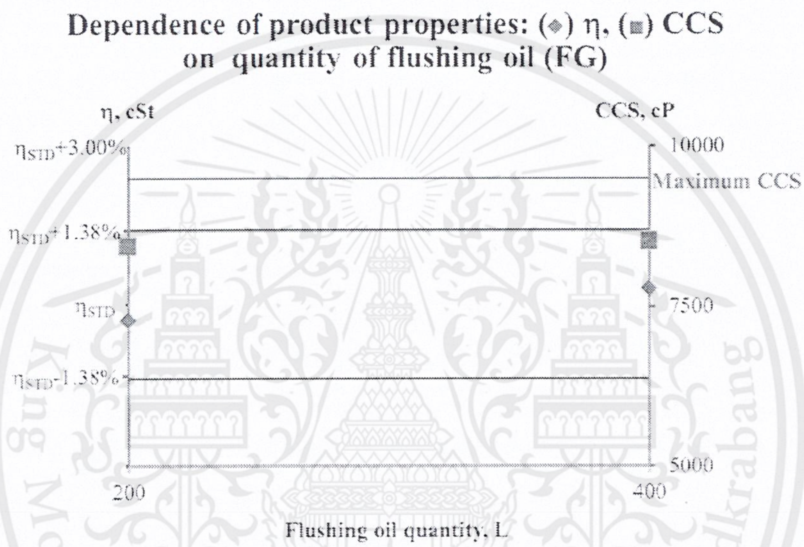

Figure 4.9 The variation of η and CCS on the quantity of the flushing oil in small packing 2

Figure 4.9 illustrates the change of viscosity during FG flushing process. Both properties passed within the determined condition at the first cycle.

From Figure 4.10, metal M1 content was in the range between $M1_{STD}$ -7% and $M1_{STD}$ +7% at the first cycle flushing. When using 200 L of flushing oil, metal M2 content is in range between $M2_{STD}$ -9% and $M2_{STD}$ +9%, while metal M3 content is in range between $M2_{STD}$ and $M2_{STD}$ -18%.

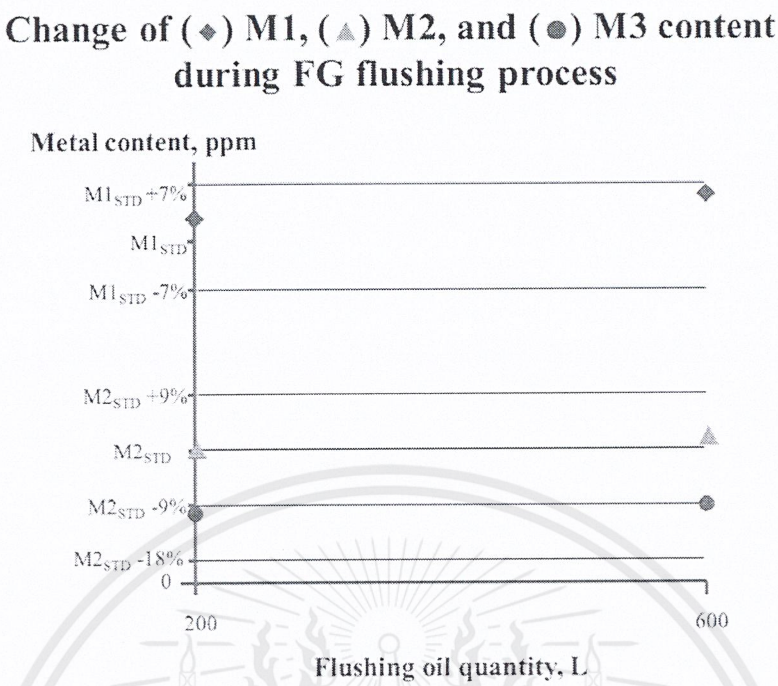

Figure 4.10 Change of metal content during FG flushing process in small packing 2

In summary, 600 L of base oil and 200 L of finished goods were suitable for flushing process of severe cross contamination case.

4.2.1.2. Standard used for flushing in small packing 2

Into This Product →

Cross Contamination from This Product		Zinc containing Engine Oils				ATF
		04a	04b(i)	04b (ii)	04b(iii)	07a
ATF	07a	BO 600 L/ FG 200 L	BO 600 L/ FG 200 L	BO 600 L/ FG 200 L	BO 600 L/ FG 200 L	Same product (No flushing)
2-stroke oils	10b	BO 600 L/ FG 200 L	BO 600 L/ FG 200 L	BO 600 L/ FG 200 L	*** BO 600 L/ FG 200 L	BO 600 L/ FG 200 L

Figure 4.11 Standard used for flushing in small packing 2

Figure 4.11 represents the standard used for filling line flushing in small packing 2.

4.2.2. Small packing 3

Four batch changes are operated in small packing 3. The results are as following:

4.2.2.1. The 1st sample

Batch change from product family 04b (i) to family 04b (i) is in case of severe cross contamination with fully-synthetic base oil in next product. Hence, BO flushing process following with FG flushing process must be done.

1) BO flushing process

Due to fully-synthetic base oil in next product, BO flushing process is done to maintain kinematic viscosity and low temperature viscosity. BO flushing process is separated into four flushing cycles. 200 L of flushing oil is applied for all flushing cycles.

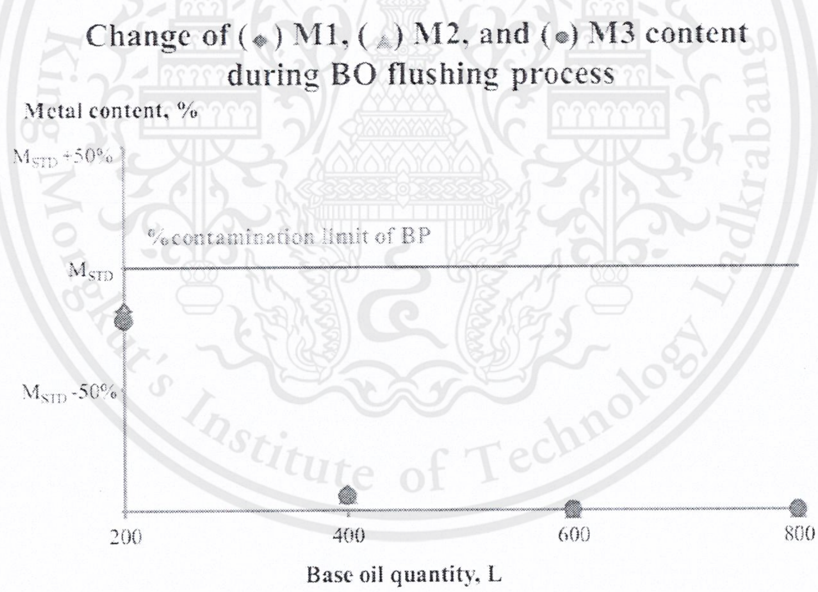

Figure 4.12 Change of metal content during BO flushing process in the 1st sample of small packing 3

Figure 4.12 presented that both metal M1, M2, and M3 contents are less than %contamination limit of BP at using only 200 L. Metal M2 is eliminated from BO flushing process. Despite of passed specification of metal content at 200 L of flushing oil, color of flushed oil failed. From the oil appearance observation, 800 L of flushing oil is proper to clean the oil residual color.

Accordingly, 800 L of flushing oil is properly applied for BO flushing process in case of severe cross contamination in small packing 3.

2) FG flushing process

Three flushing cycles are tested and 100 L of finished goods is used for each cycle.

300 L of flushing oil is proper flushing oil quantity for FG flushing process since kinematic viscosity of using 300 L of flushing oil passed within the determined condition of kinematic viscosity deviation, as shown in Figure 4.13. In addition, other specifications pass at using 300 L of flushing oil. When using 200 L of flushing oil, metal M1 content is in accordance with product formula and metal M2 content is in range between $M2_{STD}$ -7% and $M2_{STD}$ +7%, while metal M3 content is in range between $M2_{STD}$ -19% and $M2_{STD}$ -7%, as shown in Figure 4.14.

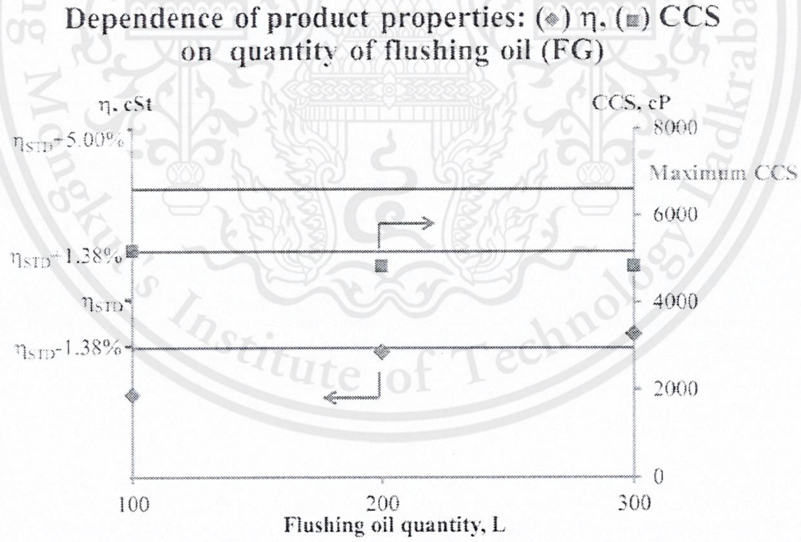

Figure 4.13 Change of η and CCS during flushing process in the 1st sample of small packing 3

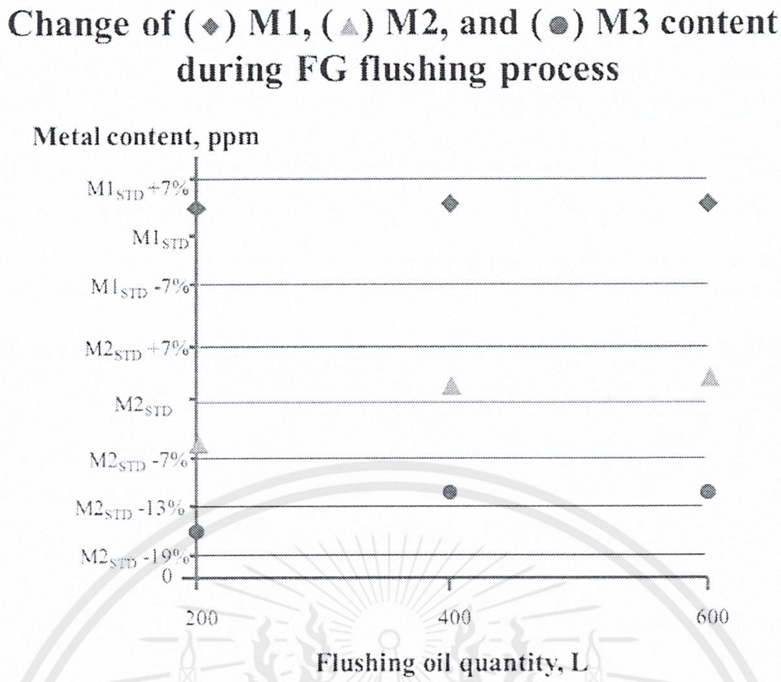

Figure 4.14 Change of metal content during FG flushing process the 1st sample of small packing 3

4.2.2.2. The 2nd sample

Batch change from product family 04b (ii) to family 04b (i) is in case of severe cross contamination which main base oil of next product is not fully-synthetic. Only FG flushing process is necessary for this case. Three flushing cycles are tested and 200 L of finished goods is used for each cycle.

400 L is proper for FG flushing process. From Figure 4.15, both viscosities passed within the determined condition when 400 L of finished goods is used for flushing process. Most of low temperature viscosity passed if difference of kinematic viscosity is not too much. Besides, metal M1 content is in range of product formula (Figure 4.15). Metal M2 content is in range between $M2_{STD}$ -12% to $M2_{STD}$ +12%, whereas metal M3 content is in range between $M2_{STD}$ to $M2_{STD}$ +24% when 200 L of flushing oil is used, as illustrated in Figure 4.16.

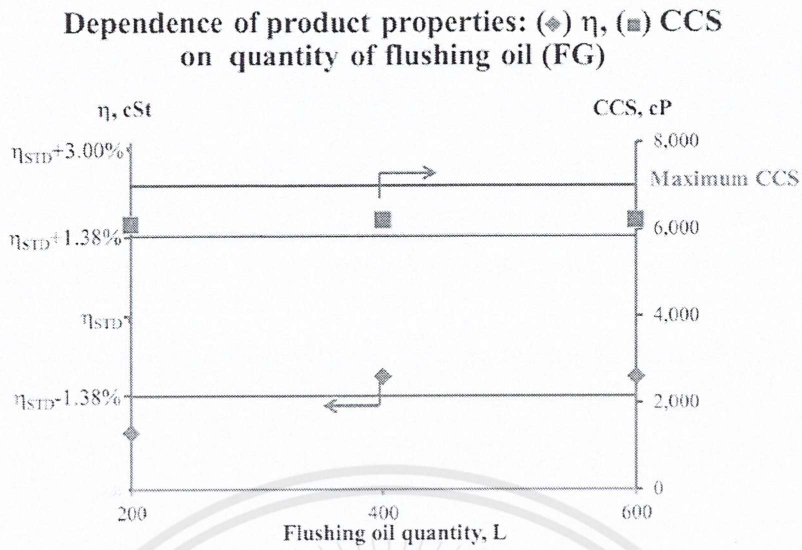

Figure 4.15 Change of η and CCS during flushing process in the 2nd sample of small packing 3

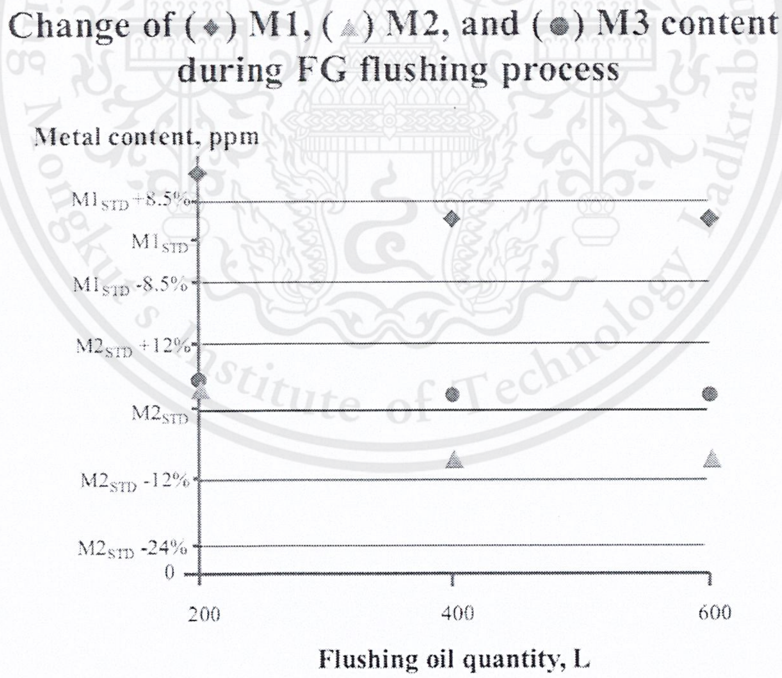

Figure 4.16 Change of metal content during FG flushing process the 2nd sample of small packing 3

4.2.2.3. The 3rd sample

This sample is in general group of the acceptable level of contamination. Main base oil composition of the next product is not fully-synthetic. Hence, only FG flushing process was used in this sample. FG flushing process had carried out into three cycles by using 200 L of finished goods for each cycle.

From observation, flushed oil color passed within the determined color of the next product at the first cycle.

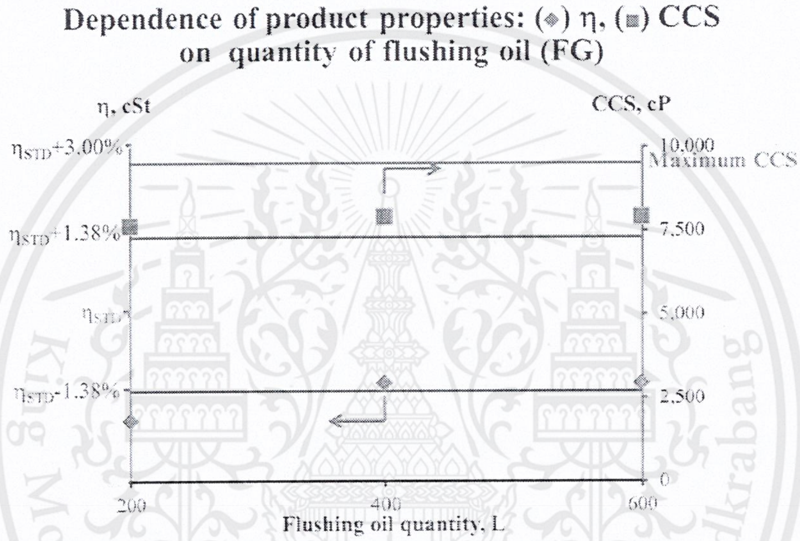

Figure 4.17 The variation of η and CCS on the quantity of flushing oil in the 3rd sample of small packing 3

Figure 4.17 represents the variation of η and CCS on the quantity of the flushing oil. The determined condition of η is the η must be in the deviation range of η_{STD}. The η of flushed oil sample met the deviation range of η when 400 L of flushing oil is used. For CCS, the viscosity must be lower than the maximum CCS at 9,500 cP. The CCS of all flushed oil samples was lower than the maximum CCS.

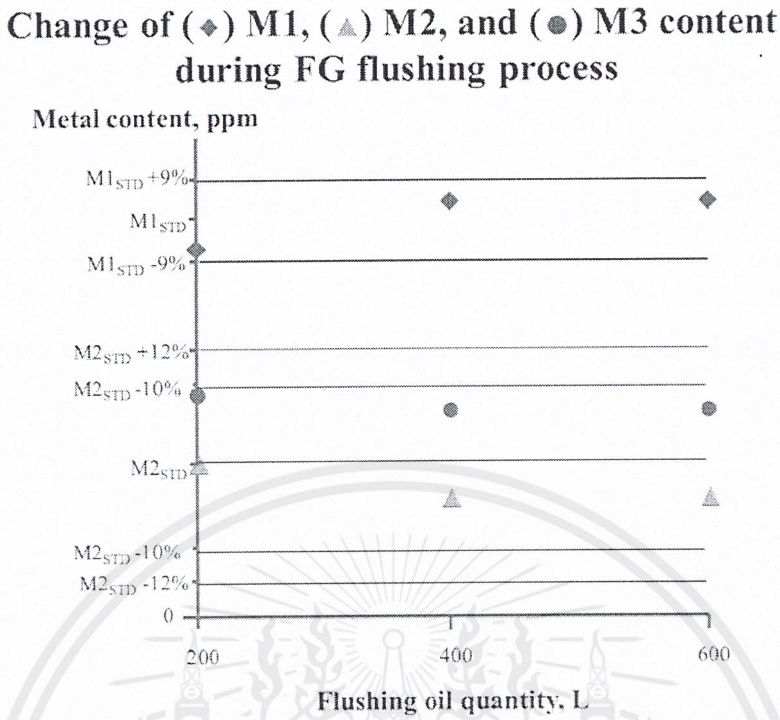

Figure 4.18 Change of M1, M2, and M3 contents during FG flushing process in the 3rd sample of small packing 3

Figure 4.18 illustrates change of metal content during FG flushing process. Metal content must be in acceptable range of metal content standard. Metal M1 passed within the determined condition of $M1_{STD}$ deviation. All of samples of metal M2 were in the range between $M2_{STD}$ -12% to $M2_{STD}$ +12%, All of samples of metal M3 were in the range between $M2_{STD}$ -10% to $M2_{STD}$ +10%.

To optimize the quantity of flushing oil for this flushing process and maximize the efficiency of this plant, 400 L of finished goods is the proper quantity of flushing oil used for FG flushing process since all of the product specification, especially in η, met their determined conditions.

4.2.2.4. The 4th sample

Metal M2 content decreases from the previous product to next product, while metal M3 must be eliminated in batch change from product family 04b (i) to family 04a. Only FG flushing process is necessary for this case. Three flushing cycles are tested and 100 L of finished goods is used for each cycle.

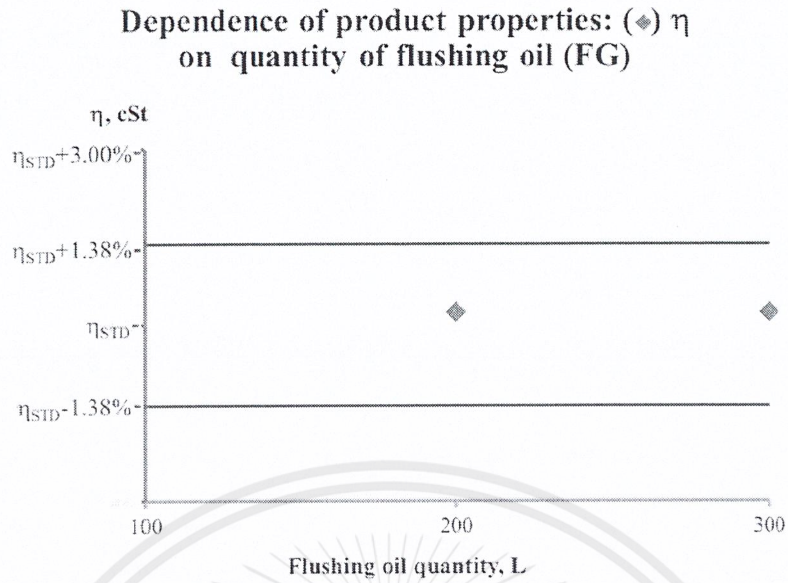

Figure 4.19 The variation of η and CCS on the quantity of flushing oil in the 4th sample of small packing 3

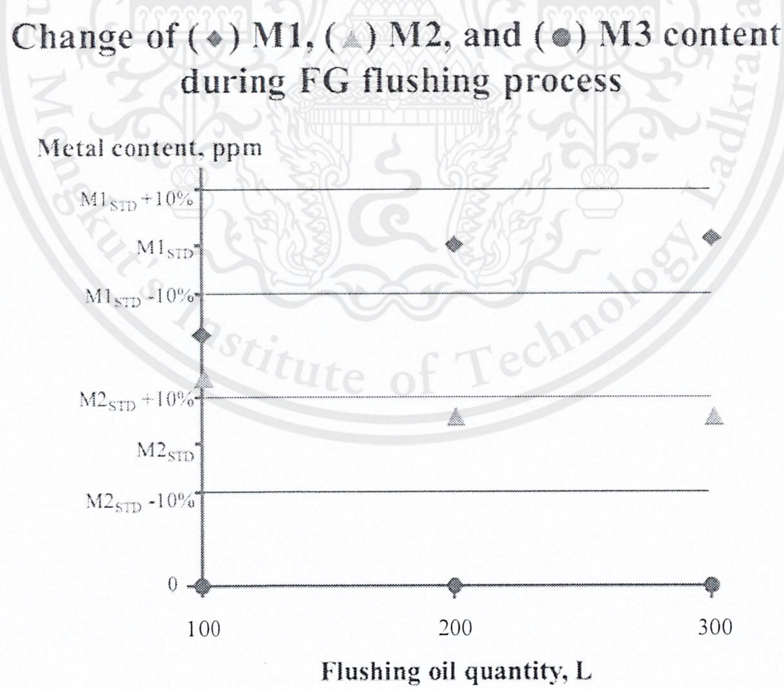

Figure 4.20 Change of M1, M2, and M3 contents during FG flushing process in the 4th sample of small packing 3

200 L is proper for FG flushing process. Sample color passed in the first cycles. Low temperature viscosity examination in this case did not perform since the viscosity grade of next product is not winter grade. Kinematic viscosities passed when 200 L of flushing oil is used, as shown in Figure 4.19. From Figure 4.20, Metal M1 and M2 contents were in range of product formula at using of 200 L of flushing oil. On the other hand, metal M3 was removed after the first flushing cycle was done.

4.2.2.5. Standard used for flushing process in small packing 3

Into This Product →

Cross Contamination From This Product ↓

		Zinc containing Engine Oils			
		04a	04b(i)		04b(ii)
			Products containing fully-synthetic oil	Products without fully-synthetic oil	
Zinc containing Engine Oils	04a	FG 400 L	BO 800 L/ FG 300 L	FG 400 L	FG 400 L
	04b (i) Products containing fully-synthetic oil	*** FG 300 L	BO 800 L/ FG 300 L	*** FG 400 L	*** FG 400 L
	04b (i) Products without fully-synthetic oil	FG 300 L	*** BO 800 L/ FG 300 L	FG 400 L	FG 400 L
	04b (ii)	FG 300 L	*** BO 800 L/ FG 300 L	FG 400 L	*** FG 400 L

Figure 4.21 Standard used for flushing process in small packing 3

After the experiments were performed for the case of current product which did not meet their specification, standard used in small packing 3 has been created based on the results from representative batch change.

In the column, the list of previous product family group has presented and, in the row, the list of next product FG has presented. The color shade in each cell represents the level of acceptable cross contamination.

The symbol of "***" indicates the example shown before.

4.2.3. Gear bulk

The most problem occurring in gear bulk filling process is batch change from product SAE 60 or SAE 50 to product SAE 10W. It results from kinematic viscosity change from high to low ($\eta_{previous} \geq 3\eta_{next}$). As a result, BO flushing process following with FG flushing process is necessary for this case.

Batch change from product family 06b-SAE 60 to product family 06b-SAE 10W is chosen since the change of kinematic viscosity is huge ($\eta_{previous} \geq 6\eta_{next}$). BO flushing process had carried out into three cycles by using 1,000 L of base oil for the first cycle and 200 L of base oil for the other cycles.

From observation, using 1,600 L of base oil for this BO flushing process is sufficient to meet the base oil color after flushing.

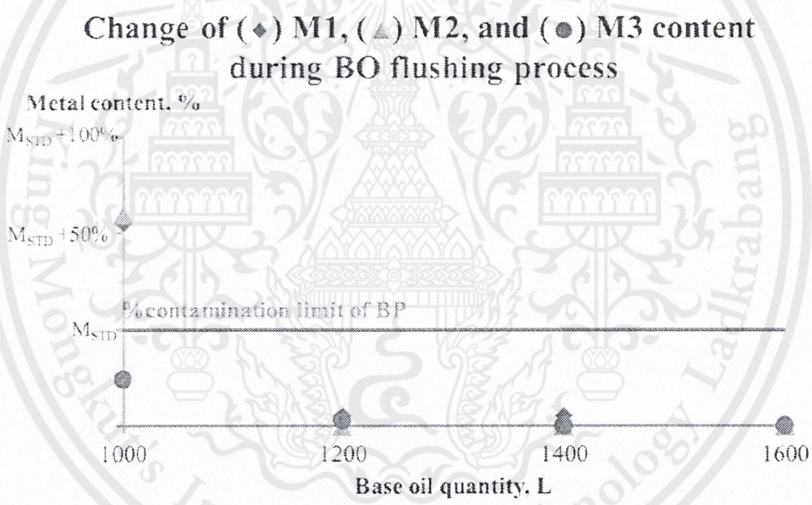

Figure 4.22 Change of M1, M2, and M3 contents during BO flushing process in gear bulk

Metal M1and M2 contents were lower than metal content standard of BP at using 1,200 L of base oil, whereas 1,000 L of base oil is enough to reduce Metal M3 content into the BP range, as given in Figure 4.22.

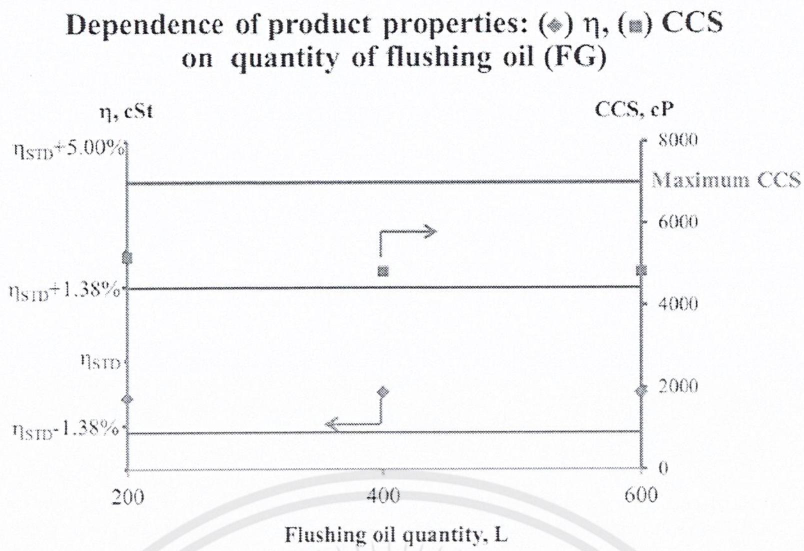

Figure 4.23 The variation of η and CCS on the quantity of flushing oil in gear bulk

Figure 4.23 represents the variation of η and CCS on the quantity of the flushing oil. The determined condition of η is the η must be in the deviation range of η_{STD}, whereas the CCS must be lower than the maximum CCS at 7,000 cP. All of the flushed oil samples passed within the determined condition of η and CCS respectively.

Change of metal content during FG flushing process. Metal content must be in acceptable range of metal content standard. Metal M1and M2 content passed within the determined condition of $M1_{STD}$ deviation and $M2_{STD}$ deviation respectively, as shown in Figure 4.24.

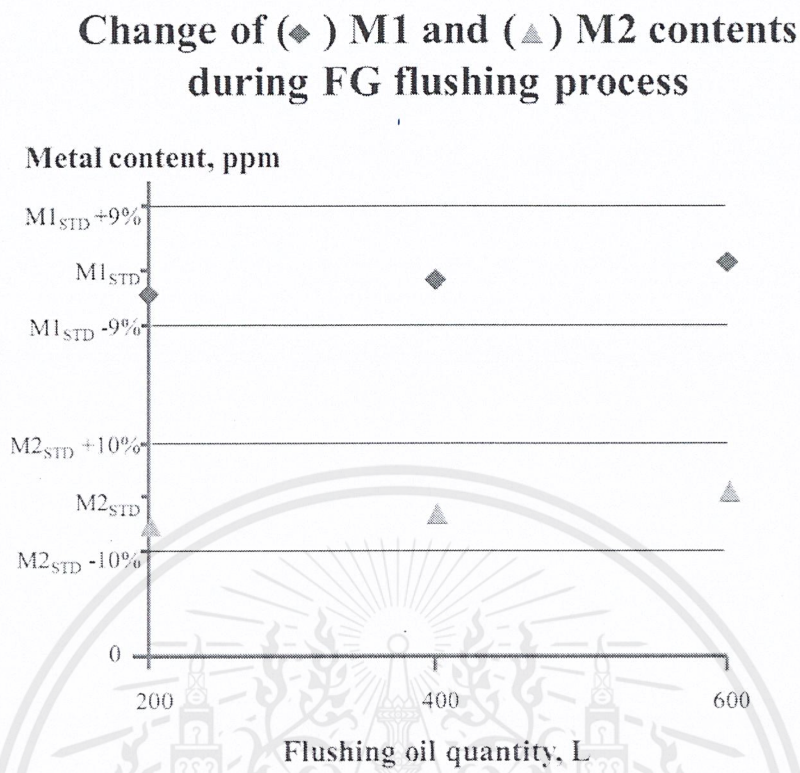

Figure 4.24 Change of M1, M2, and M3 contents during FG flushing process in gear bulk

To optimize the quantity of flushing oil for this flushing process and maximize the efficiency of this plant, 1,600 L of base oil was sufficient to meet the color and metal content in accordance with the standard of the BP Castrol for the BO flushing process. 200 finished goods was the proper quantity of flushing oil used for FG flushing process since all of the product specification met their determined conditions.

Into This Product ----->

Cross Contamination From This Product

		06b-Gear oils			
		SAE 10W	SAE 30	SAE 50	SAE 60
06b-Gear oils	SAE 10W	Same product (No flushing)	FG 200 L	FG 200 L	FG 200 L
	SAE 30	FG 200 L	Same product (No flushing)	FG 200 L	FG 200 L
	SAE 50	BO 1,600 L / FG 200 L	FG 200 L	Same product (No flushing)	FG 200 L
	SAE 60	*** BO 1,600 L / FG 200 L	FG 200 L	FG 200 L	Same product (No flushing)

Figure 4.25 Standard used for flushing process in gear bulk

Figure 4.25 illustrates the standard used for flushing process in gear bulk.

4.2.4. Engine bulk

4.2.4.1. The 1st sample

This is a batch change from product family 04b(i) to family 04b (i). This sample is in group of 0.1-0.2% acceptable contamination level. Main base oil composition of the next product is not fully-synthetic. Hence, only FG flushing process was used in this sample. FG flushing process had carried out into three cycles by using 150 L of finished goods for the first cycle and 50 for the other cycles.

From observation, flushed oil color passed within the determined color of the next product at the first cycle.

The determined condition of η is the η must be in the deviation range of η_{STD}, whereas the CCS must be lower than the maximum CCS at 7,000 cP. All of the flushed oil samples passed within the determined condition of η and CCS respectively, as shown in Figure 4.26.

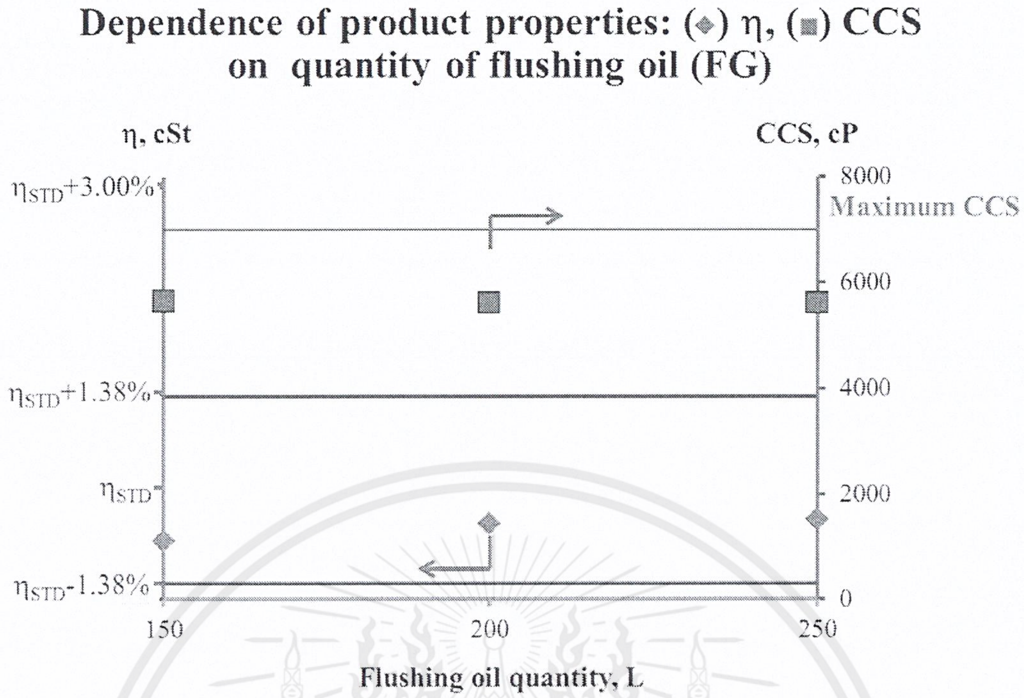

Figure 4.26 The variation of η and CCS on the quantity of flushing oil in the 1st sample of engine bulk

Change of metal content during FG flushing process. Metal content must be in acceptable range of metal content standard. Metal M1and M2 content passed within the determined condition of $M1_{STD}$ deviation and $M2_{STD}$ deviation respectively, as shown in Figure 4.27.

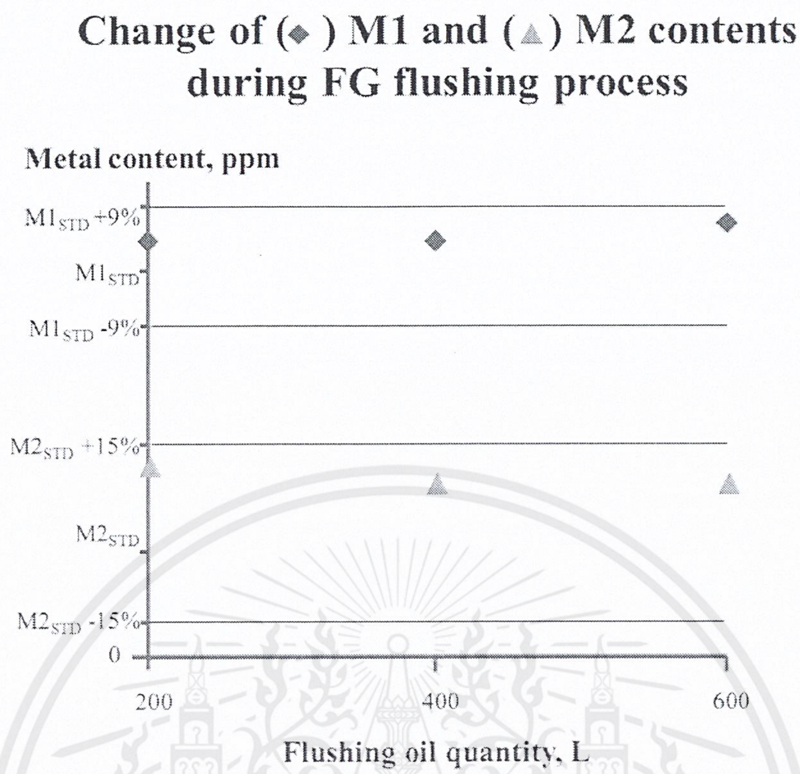

Figure 4.27 Change of M1, M2, and M3 contents during FG flushing process in the 1st sample of engine bulk

To optimize the quantity of flushing oil for this flushing process and maximize the efficiency of this plant, 150 finished goods was the proper quantity of flushing oil used for FG flushing process since all of the product specification met their determined conditions.

4.2.4.2. The 2nd sample

This is a batch change from product family 04b(ii) to family 04b (i). This sample is in group of 0.1-0.2% acceptable contamination level. Main base oil composition of the next product is not fully-synthetic. Hence, only FG flushing process was used in this sample. FG flushing process had carried out into four cycles by using 150 L of finished goods for the first cycle and 50 for the other cycles.

From observation, the first cycle is sufficient to meet the product color of the finished goods.

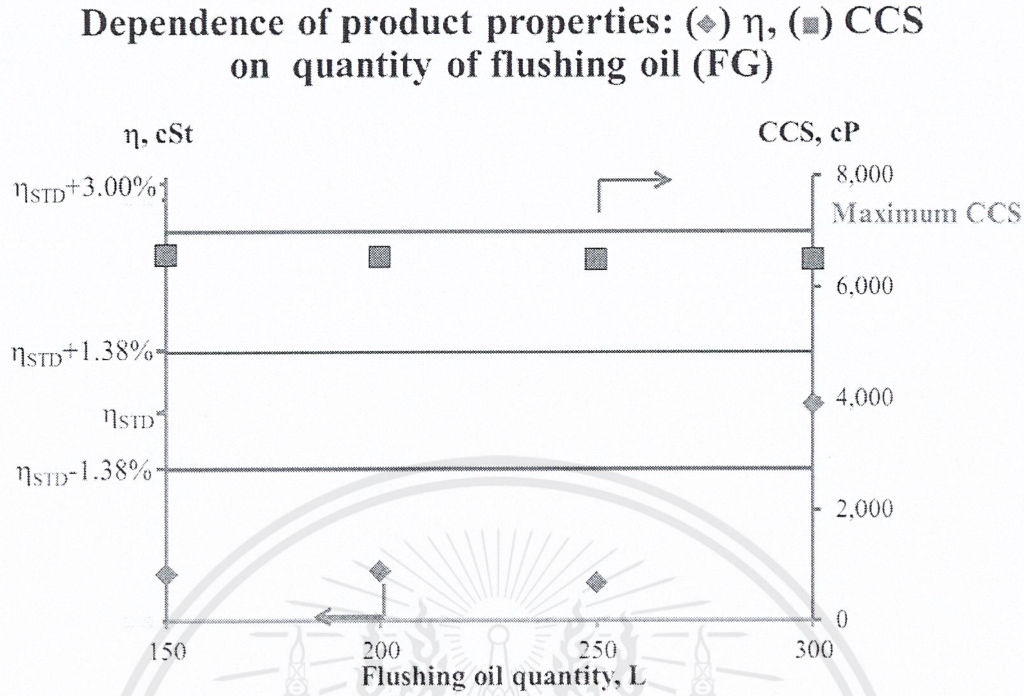

Figure 4.28 The variation of η and CCS on the quantity of flushing oil in the 2nd sample of engine bulk

Figure 4.28 illustrates the variation of η and CCS on the quantity of flushing oil in the 2nd sample of engine bulk. For CCS, All of the flushed oil samples were lower than the maximum CCS, so all of the samples passed within the determined condition. The η of this representative met the deviation of kinematic viscosity when 300 L of finished goods was used.

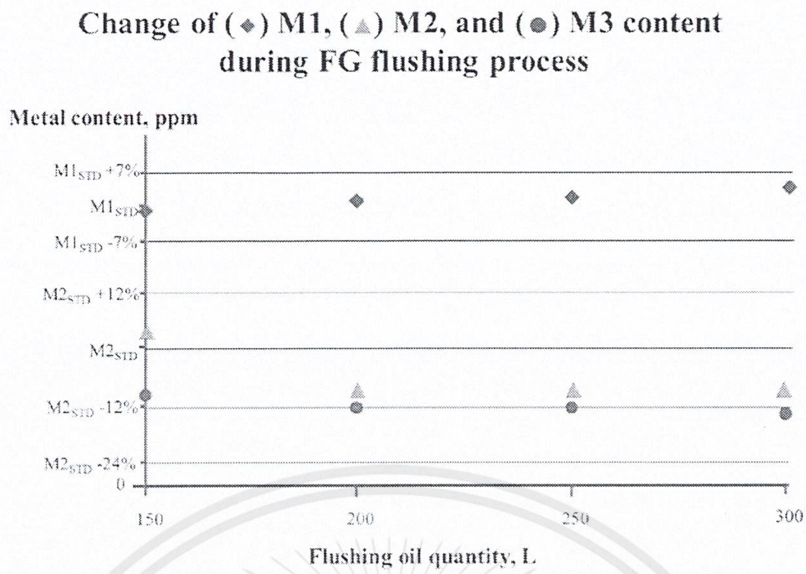

Figure 4.29 Change of M1, M2, and M3 contents during FG flushing process in the 2nd sample of engine bulk

Figure 4.29 shows the change of metal content during FG flushing process. Metal content must be in acceptable range of metal content standard. For metal M1 content, M1 content must be in the range between $M1_{STD}$ -7% to $M1_{STD}$ +7%. M2 content must be in the range between $M2_{STD}$ -12% to $M2_{STD}$ +12%, while M3 content must be in the range between $M2_{STD}$ -24% to $M2_{STD}$. All of flushed oil samples passed within the determined condition.

To optimize the quantity of flushing oil for this flushing process and maximize the efficiency of this plant, 300 finished goods was the proper quantity of flushing oil used for FG flushing process since all of the product specification, especially in η, met their determined conditions.

4.2.4.3. The 3rd sample

This is a batch change from product family 04b(i) to family 04b (ii). This sample is not in the general group of the acceptable level of contamination. Hence, only FG flushing process was used in this sample. FG flushing process had carried out into four cycles by using 150 L of finished goods for the first cycle and 50 for the other cycles.

From observation, flushed oil color passed within the determined color of the next product at the first cycle.

The determined condition of η is the η must be in the deviation range of η_{STD}, whereas the CCS must be lower than the maximum CCS at 7,000 cP. All of the flushed oil samples passed within the determined condition of η and CCS respectively, as shown in Figure 4.30.

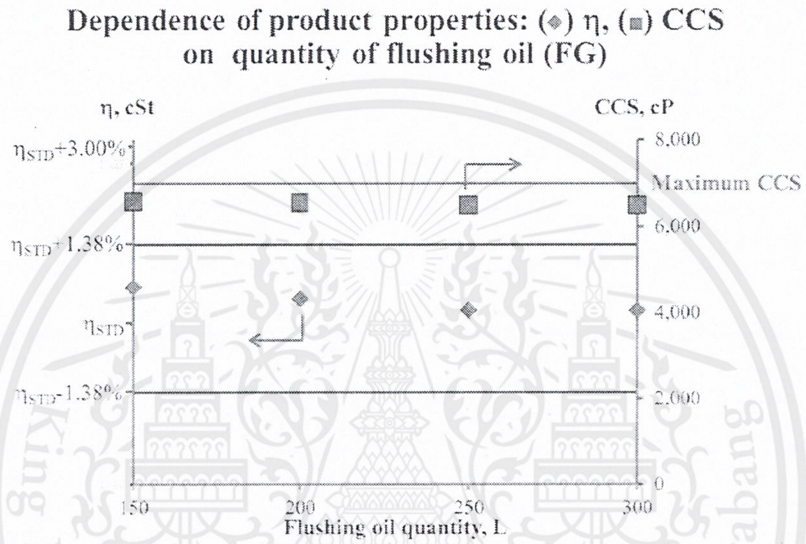

Figure 4.30 The variation of η and CCS on the quantity of flushing oil in the 3rd sample of engine bulk

Change of metal content during FG flushing process. Metal content must be in acceptable range of metal content standard. For metal M1 content, M1 content must be in the range between $M1_{STD}$ -7% to $M1_{STD}$ +7%. M2 content must be in the range between $M2_{STD}$ -5% to $M2_{STD}$ +5%, while M3 content must be in the range between $M2_{STD}$ -12% to $M2_{STD}$ +12%. All of flushed oil samples passed within the determined condition, as illustrated in Figure 4.31.

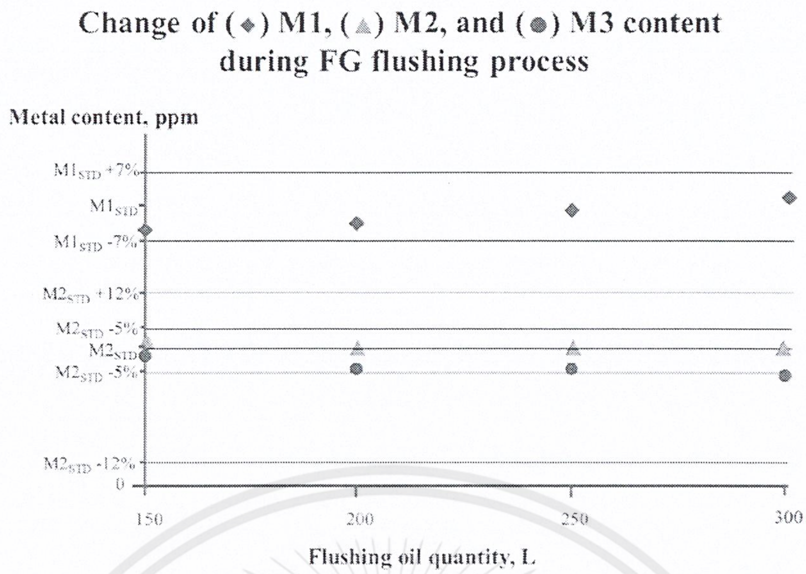

Figure 4.31 Change of M1, M2, and M3 contents during FG flushing process in the 3rd sample of engine bulk

To optimize the quantity of flushing oil for this flushing process and maximize the efficiency of this plant, 150 finished goods was the proper quantity of flushing oil used for FG flushing process since all of the product specification met their determined conditions.

4.2.4.4. Standard used for flushing process in engine bulk

Cross Contamination From This Product / Into This Product		Zinc containing Engine Oils	
		04b(i)	04b(ii)
Zinc containing Engine Oils	04b(i)	*** 150	*** 150
	04b(ii)	*** 300	Same product (No flushing)

Figure 4.32 Standards used for flushing process in engine bulk

Figure 4.32 illustrates the standard used for flushing process in gear bulk.

4.3. Evaluation of flushing oil optimization in problem case II

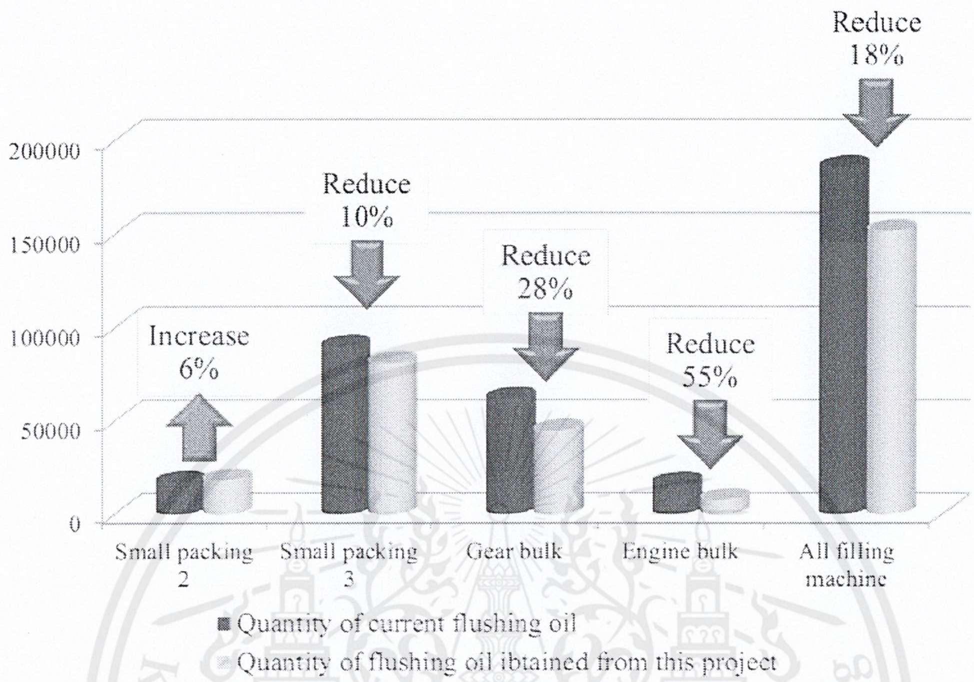

Figure 4.33 The quantity of the flushing oil comparison

Figure 4.33 presented that flushing oil quantity in each filling line decreased except small packing 2. In small packing 2, 6% of flushing oil increased to prevent product off-spec in group of severe cross contamination. 10%, 28%, and 55% of flushing oil quantity reduced in small packing 3, gear bulk, and engine bulk, respectively. In the overall of the flushing process in problem case II, 18% of flushing oil quantity is saving per year.

Chapter V
Conclusion

In summary, the proper quantity of the flushing oil used for each batch change was determined and performed in the standards used for filling line flushing. Finished goods which did not meet their specification after flushing process are eliminated. In addition, 18% of flushing oil quantity is saving per year.

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