

cluch facing

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Best Practice of Striving Energy Sustainability in A Hot Press Machine for Clutch Facing Manufacture)

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ABSTRACT

A facing clutch manufacturer in Surabaya, Indonesia, PT. X uses 20 hot press machines to produce the facings. The required heating process is provided by heat transfer oil (HTO), which is heated by natural gas burned in a heater. PT. X wants to reduce its natural gas consumption. The assessment started with checking the insulation on the piping system, measuring the temperature in the hot press machines, and measuring the HTO flow rate. The insulation in the piping system is in good condition. From the measurement, it was found that the HTO flow rate is adequate and fits the need of the heating process. Another finding is that the surface temperature of the lower plate in shaft no. 4 is the lowest than in the other shafts. The existing (asbestos) insulation from the lower bed in shaft no 4 to the hydraulic component is only 3 mm thick. This is not enough to prevent heat loss from the bed in shaft no. 4. The new 18-mm asbestos replaced the old asbestos. The replacement shows that the temperature at the mold surface at shaft no. 4 increased from 162.6°C to 170.9°C on average for MC-02 and from 166.7°C to 173.1°C on average for MC-03. Another achievement obtained is that the natural gas consumption was reduced by around 7.3% or 39 MMBtu/month, or equivalent to reducing 0.312 metric tons of CO₂ per month. This is a simple effort to use less energy to protect our environment.

1. Introduction

Clutches are used in automotive, railway, transit coach, motorcycle, construction machinery, and agricultural industries to help control speed and gear shifting in vehicles ranging from tractors to race cars. The materials for the clutch must be strong and able to resist wear effects as might be accrued from scoring, galling, and ablation. It can be fiber, elastomeric, ceramic, graphite, or metal alloy. The clutch will smoothly transmit the motion of two separate elements rotating at different speeds on the same axis. There are several types of clutches, such as positive clutch, friction clutch, disk clutch, and centrifugal clutch. The main mechanism of the vehicle clutch is the disk clutch. Disc clutches can be designed for dry or wet operation. Dry design is used for automotive clutches, but wet designs are used for multiple applications. The oil is used as a cooling medium and reduces friction (1), (2), (3). There are several functions of a clutch, such as transmitting the torque from the engine to the drivetrain, smoothly delivering the power from the engine to enable smooth vehicle movement, performing quietly, and reducing drive-related vibration (4), (5). To switch gears, a clutch is used to engage and disengage the drive shaft in the engine. The illustration is given in Fig. 1. When the clutch is engaged, power can be transferred to the transmission and the flywheels from the engine.



Fig. 1. An illustration of clutch working principle (5)

Developments in the car's overall architecture design tend toward a reduction in the powertrain volume. The concept of interior spaciousness aims at maximizing the space dedicated to passengers without increasing vehicle length or width. The only solution for a normal clutch system would be to lengthen the pedal stroke. Unfortunately, this solution is inadmissible because of ergonomic constraints and because it would consume precious centimeters in the driver's seat's longitudinal position, reducing the interior volume. The increase in the engine output peak torque leads to the introduction of higher-capacity clutches (4).

Here is some research related to the clutch. Delprete et al. analyze the clutch axial dynamic effects on abuse load condition. The analysis is performed by building an engine-flywheel-clutch-inertial load model in MATLAB/Simulink environment. The clutch model is as detailed as possible, and it considers the inertial and elastic effects of all components involved both in axial and torsional behavior (6). Ompusunggu et al. present the development of a condition monitoring method for wet friction clutches, which might be useful for automatic transmission applications. The method is developed based on quantifying the change of the relative rotational velocity signal measured between the input and output shaft of a clutch. The sensors typically available in automatic transmissions i.e., pressure and velocity sensors, can be employed for extracting the proposed features (7).

One of the components of the clutch disk is the clutch facing, the part that experiences friction. The clutch facings ensure the gears do not grind against each other during this process, reduce the noise caused by the operation of clutches, and provide elasticity and support. Fig. 2 shows the components of a clutch. The facings will inevitably wear down to endure the tension of the process and the high temperature, especially if they consistently ensure high speeds. Therefore, the facings need to be periodically checked and replaced if necessary to ensure that protective elements are still intact and that optimum performance is achieved.

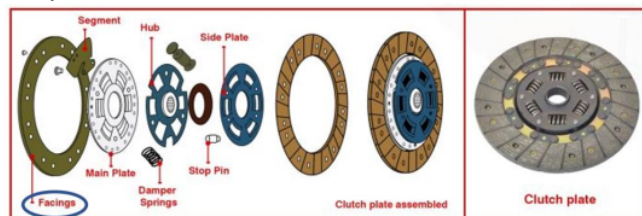


Fig. 2. The components of a clutch (8)

Clutch facings can be manufactured from a range of materials depending on the application, and some of the most common are asbestos, woven fibre such as Kevlar or aramid, and ceramic materials. As shifting gears generate heat, these materials must account for thermal expansion and remain constant at a range of temperatures, have high heat capacity, and have good thermal conductivity (9), (10), (3). A woven organic clutch can be used for daily drive, and ceramic is best for racing (10). The clutch can be made of commercial paper-based friction materials. It was subjected to adhesive

wear and thermal degradation, and dry frictional characteristics. Adhesive wear and thermal degradation are the main mechanisms in paper-based friction materials. These two degradation mechanisms are inevitably present in practice, where the dominance depends on the operating condition. The experimental results reveal that both adhesive wear and thermal degradation have opposite effects on the frictional characteristics, where the static and kinetic coefficients of friction increase due to adhesive wear but decrease due to thermal degradation (11). Recently, the automotive industry has been widely using polymers and polymer composites. Polymer composites can be divided into thermoset and thermoplastic materials. The clutch-facing materials are classified as thermosets. The formation of thermoset materials can use methods such as liquid composite molding, compression molding, sheet molding compounds, or bulk molding compounds (12).

Designing a friction clutch assembly using Pro-e software and its structural analysis using ANSYS software. Modal analysis is done to optimize the natural frequency of the single plate friction clutch to avoid being in resonance with the engine frequency range. The results show that the natural frequencies of the original model and the natural frequencies of the simplified model are in good agreement with each other (13). Conventional transmission systems using single plate clutch must perform 15 operations to shift from low speed to high speed; out of the 10 operations are clutch operations. Hence making clutch operations automatic will reduce human effort. The auto-disengagement single clutch employs only one set of compression springs instead of the usual two sets. This arrangement keeps the clutch in a normally disengaged condition, unlike the conventional clutch that is in an engaged condition and must be disengaged by a manual Lever (14). Vitnor and Kavade present a finite element analysis of the grooved friction plate of the Diaphragm spring Clutch, which has been used to study temperature distribution & thermal stresses during a single engagement. The commercial software CATIA V.5 & ANSYS 15 is used for the modeling of clutch parts & Thermo-mechanical analysis of friction plate, respectively. The temperature increases from the inner radius to the outer radius; hence there is always a maximum temperature at the outer radius (15). Sfarni et al. investigate the behavior of the riveted clutch disc assembly (cushion disc, rivets, and riveted facings), which allows a soft gradual re-engagement of torque transmission. This progressive re-engagement obtained by the clutch disc characteristics in the axial direction preserves the driver's comfort and avoids mechanical shocks increasing the lifespan of the engine. A Finite Element model to design new clutch discs to predict the cushion curve, a thin-waved sheet located between the two facings and fixed by rivets. The cushion curve acts like a spring allowing a soft gradual re-engagement. The results presented concern the prediction of contact pressures of a new riveted clutch disc at the facings interface with the cushion curve (16).

Below are some papers discussing the cooling or heating process in a narrow channel or passage, but it is still related to the hot press machine. Kumar et al. stated that cooling plays an important role in hot working products' quality and production rate. The reason for the low productivity of the diaphragm hot forming line is that the cooling time takes a long time in the hot forming process. They opted for new tools with the increase in the thickness of the cooling jackets. Hence the cooling rate will be higher with an increase in the flow of cooling fluid through the larger cooling jackets (17). Ng et al. did a numerical simulation on the heat transfer phenomenon within the HPF die through the application of ANSYS Fluent. The cooling rate and temperature distribution throughout the hot press forming process were successfully discussed and evaluated. The research has concluded that the biggest size diameter with a circular shape and nearest to the location of the cooling channel was proposed to be the best cooling rate and the most economical (18).

The formation of clutch facing is carried out by the compression molding process because it has several advantages, such as short cycle times, reproducibility, and dimensionally stability. A hot press machine is used for the compression molding process, during which the process is accompanied by

the addition of heat. The heat required can range from 180-200°C (19). Mold design on a hot press machine is an important factor affecting product quality, production efficiency, and costs. While heating temperature, heating time, compression pressure, and holding time are process parameters that need attention (20).

There are three old patents about making clutch facing⁴. First, a method of manufacturing a clutch facing including the steps of mixing graphite and phenolic resin to form a graphite mixture, soaking an asbestos fiber string within the mixture, removing the soaked string such that phenolic resin content of between 14-24 weight percent and graphite content of between 1-8 weight percent for every 100 weight percent is produced and bonding the string to the clutch facing such that the Rockwell hardness of the clutch facing is between 20-60 on the Moh scale. The step of bonding said string to said clutch facing includes forming said string into a loop shape. The phenolic resin comprises thermosetting resin (21). Second, two years later, Yamamoto et al. renewed the patent. A clutch-facing material, including strings of asbestos, is applied to a mixture of cashew dust resin and graphite, which is, in turn, mixed with cashew dust. The graphite is inseparably contained in the mixture of cashew dust resin and graphite and, in combination with the cashew dust, provides a clutch-facing material showing a high frictional coefficient even at high temperatures (22). The clutch facing was still made of asbestos. Third, Kamiura and Natori had the invention to provide a process for producing clutch facings exhibiting good performances (1) without the use of asbestos and a large amount of solvent in the production steps, (2) using a rubber composition to adhere uniformly to a substrate of glass fibers and the like, (3) no cutting or tearing occurs in the step of forming the rubber composition into a sheet (23).

As the automotive, construction machinery, and agricultural industries increase, the demand for clutch facing also increases. There is a factory in Surabaya – Indonesia, called PT. X, that produces clutch facing that operates continuously. There are 20 hot press machines to produce the clutch facings. The heat source for all machines comes from natural gas burned in a heating section, which is called a heat transfer oil – HTO heater in PT. X. The HTO is heated in HTO heater and then circulated to all machines to produce the facings. There are several upper, lower (or bottom) plates and mold in each machine. The construction and the photograph of a hot press machine used in PT. X is shown in Fig. 3. Heat transfer occurs in conduction between the upper and bottom side plates and convection heat loss to the surrounding. On the bottom plate, the raw material is placed on a mold. The heat will transfer from the bottom plate to the product. The temperature required in the hot press machine ranges from 135-175°C, depending on the product. Yet, the HTO heater in PT. X operates at a much higher temperature, i.e., 220°C. It is crucial to evaluate whether the temperature setting in the HTO heater can be lowered. If the setting can be lowered, energy consumption can be reduced. Thus, we can strive for energy sustainability.

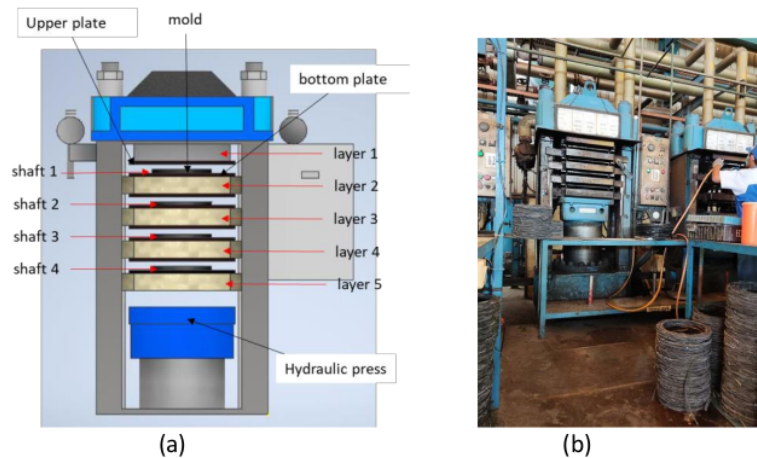


Fig. 3. The hot press machine in PT. X (a) construction, (b) photograph

2. Methodology

Analysis is conducted based on data measured on the plant in PT. X from August until November 2022. The first thing to examine is the piping system where oil circulates from the HTO heater to all hot press machines. Almost all piping is insulated with rock wool on the outside. The thermocouple is installed only at the outlet of the HTO heater and at the bottom bed of one layer in each hot press machine. The temperature measurement was conducted at the surface of the valves that is not covered with rock wool. The thermometer used is a thermal imager FLUKE TIS20. The data of temperature collected will be used to determine if the insulation is adequate or not. The temperature was also measured at several locations, i.e., on the upper plate, bottom plate, and the mold in the hot press machine, as shown in Fig. 4. The temperature was also measured on the outer surface of the oil inlet and outlet headers.

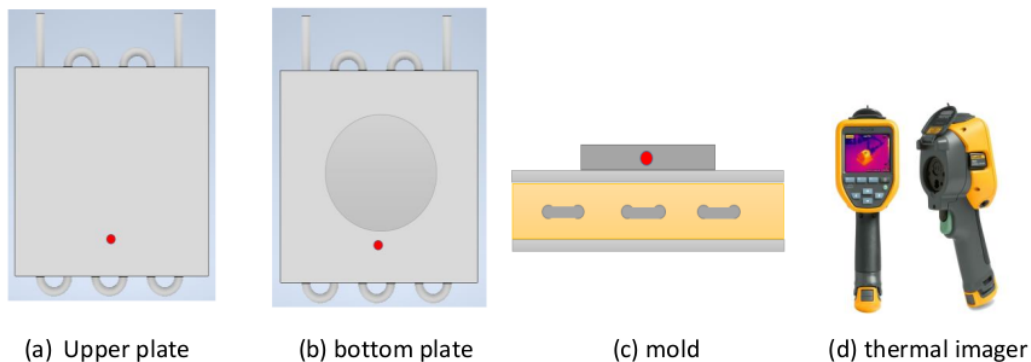


Fig. 4. Position of temperature measurement on the plates and mold

The next thing to be evaluated is the hot press machine itself. As in Fig. 3, each hot press machine in PT. X has four beds and four molds where the raw material is pressed and heated to become a

clutch facing. There is an upper plate and a lower (bottom) plate that work together to press and heat the product. The mold is located on the bottom plate. The terms used are the “shaft” to define where the mold is and the “layer” to define where the hot oil pipe is. So, there are 4 shafts and 5 layers. The hot oil flows to four shafts or beds and the top part of the first upper plate. Thus, there are five inlet pipes where oil enters the machine, and five outlet pipes leave the machine, as shown in Fig. 5. The oil is distributed into five pipes from an inlet header and sent to an outlet header before going back to the main pipe.

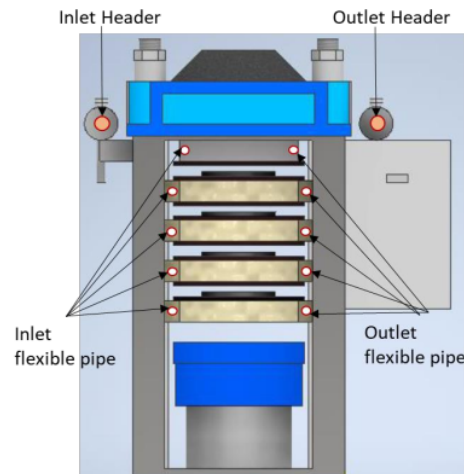


Fig. 5. The oil passages enter and leave the hot press machine

Since the heat source is oil, it is essential to get its flow rate. The assessment was conducted to check if the oil flow rate entering the beds that heat the upper and bottom plates is as required or not. The oil flow rate required depends on the product to be pressed. If the flow rate is not enough, then the temperature of the bed and plates will be lower than the setting. But if too much oil enters the bed, it is a waste.

From the data of oil temperature at the surface of the piping installation and the oil flow rate, analysis was conducted to determine the main cause of the problem in PT. X and suggest solutions to consume less energy to strive for energy sustainability.

3. Results

3.1. The temperature in the piping system

The HTO circulates from the HTO heater to all hot press machines and go back to HTO heater as shown in Fig. 6. The red and blue lines are for the oil leaving and going back to HTO heater, respectively. All pipes are covered with rockwool sheets as the pipe thermal insulation. There is no thermometer installed in the piping system. So, the possible location for measuring the temperature is on the outer surface of the bare fitting, such as the valve or cylinder of the filter. The temperature measured at points shown in Fig. 6 is tabulated in Table 1.

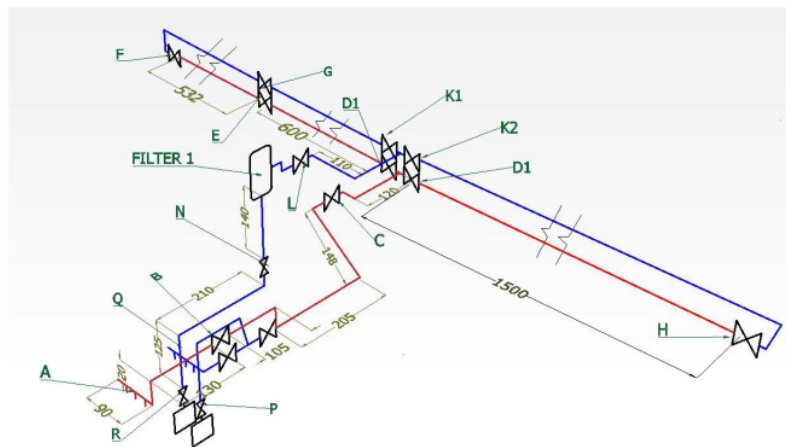


Fig. 6. The piping system for oil in PT. X

Data in Table 1 was taken when the HTO was set at 220°C. The first point of measurement as oil went out from HTO is at point A and it was 217°C. This number shows that the difference of oil temperature inside the pipe and temperature of outer surface of pipe is slightly small. The temperature measured at the outer surface can be considered the same as the oil temperature. The lowest temperature of supply oil from HTO at the piping system, i.e., the outer surface of a valve at the farthest, point H, is 210°C. The oil temperature inside must be higher. Thus, the insulation on the piping system is adequate.

Table 1. The temperature measured on the outer surface of some points in piping system

Supply oil	Temperature °C		Return oil	Temperature °C
Point A	217		Point G	204
Point B	214		Point K1, K2	208
Point C	213		Point L	208
Point D1	212		Point @ Filter 1	202
Point E	211		Point N	209
Point F	211		Point R	210
Point H	210		Point P	210

In the piping system, the oil is distributed to five flexible inlet pipes from an inlet header and then collected to an outlet header. The temperature measured at the outer surface of the inlet and outlet headers of each machine compared to the setting temperature of HTO heater are shown in Fig. 7. The inlet headers of all machines accept almost the same temperature. The temperature at the outlet header was quite different because it depended on the condition of the machine, i.e., being idle or processing the product.

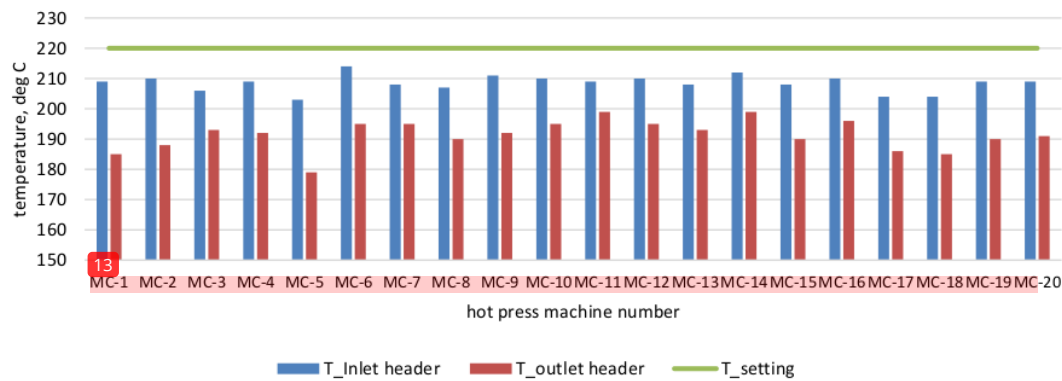
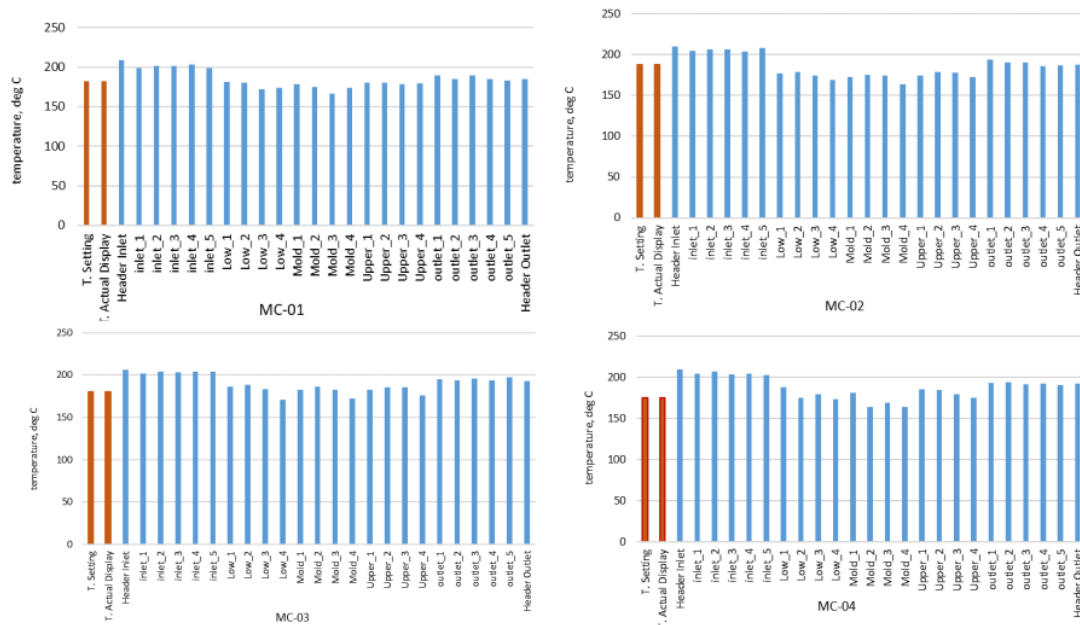


Fig. 7. The temperature at the outer surface of the at the inlet and outlet headers of each machine

There is no problem with the insulation on piping. A small suggestion for the PT. X regarding the piping is covering the bare valves or filter cylinder with rock wool insulation. The heat loss in piping system happens only on this two apparatus.

3.2. Temperature in the hot press machines

The temperature was measured on the surface of upper plate, lower plate, and on mold in each shaft in all twenty hot press machines. While the actual temperature is data taken from a thermocouple that is inserted in the lower bed in shaft four at almost all hot press machines. The position of measurement is as in Fig. 4. The result for several machines in PT. X is shown in Fig. 8 for Machine MC-01, Machine MC-02, Machine MC-03, and Machine MC-04. The results of these four machines represent other machines, because they have similar patterns.



T.Setting = the temperature that is set by the operator for a certain product.
T.Actual Display = the real temperature measured with the thermocouple.
Header inlet/outlet = the outer surface temperature at the inlet/outlet header.
Inlet_1 = the outer surface temperature at the flexible-inlet oil pipe no 1 (the top).
Inlet_2 = the outer surface temperature at the flexible-inlet oil pipe no 2, etc.
Low_1 = the surface temperature at lower plate no 1
Low_2 = the surface temperature at lower plate no 2, etc.
Mold_1 = the surface temperature of mold on bed 1
Mold_2 = the surface temperature of mold on bed 2, etc.
Upper_1 = the surface temperature at upper plate no 1
Upper_2 = the surface temperature at upper plate no 2
Outlet_1 = the outer surface temperature at the flexible-outlet oil pipe no 1 (the top).
Outlet_2 = the outer surface temperature at the flexible-outlet oil pipe no 2, etc.

Fig. 8. The temperature measured in hot press machines MC-01 until MC-04

In Fig. 8, the temperature at the inlet header of machine MC-01, MC-2, and MC-03 was at a higher temperature than the required setting. The other hot press machines also have the same temperature condition as in these three machines. After a long discussion it was found that the operator of PT. X needed to set a higher temperature, because they needed to anticipate the dropped temperature at shaft no. 4, otherwise production will fail. Fig. 8 shows that the surface temperature on the lower plate and mold are lowest at shaft no. 4, or the lower shaft in the hot press machine. This finding leads to the next step. An investigation of HTO's flow rate going to five flexible pipes is essential to be conducted.

3.3. Oil flow rate entering the hot press machine

The oil (HTO) is delivered to the inlet header before it enters five flexible pipes. From the flexible pipe, the oil enters the bed of each shaft through a passage as shown in Fig. 10. To produce facing clutch from the raw material there are two processes involved together, i.e., pressing and heating process. The pressing is done by the hydraulic piston and the heating by the upper and lower plates that are heated by oil. When the oil's flow rate is enough, then the heat rate from the bed to the upper plate, lower plate, and mold will be adequate to produce a good-facing clutch.

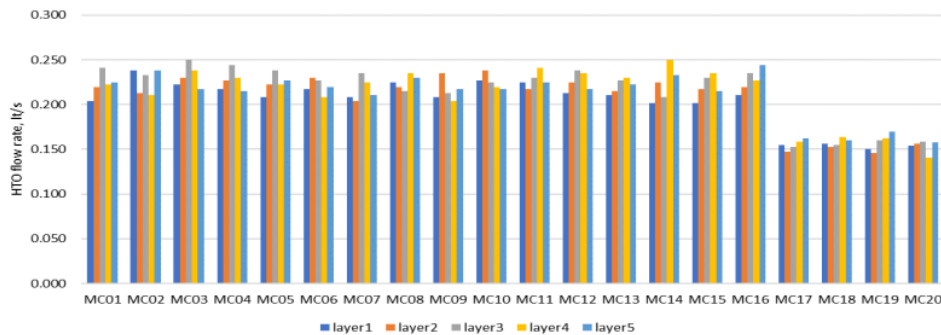


Fig. 9. The oil's flow rate from measurement

From the measurement done manually, the results are given in Fig. 9. The oil flows inside five passages with an almost uniform flow rate. So, the prediction that the oil's flow rate is smaller in layer 5 was not proven. The oil flows to machines MC-17, MC-18, MC-19, and MC-20 are smaller compared to other machines, because the configuration of the passage in the bed is different. These four machines have eight passes, but the other machines have six passes as shown in Fig. 10. The flow rate of oil with eight passes is smaller because the flow resistance is higher. How about the temperature on the beds?

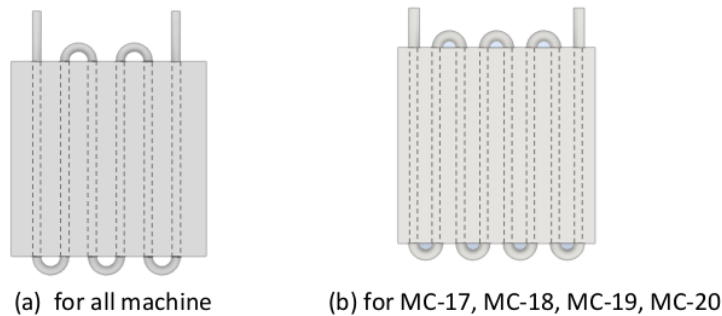


Fig. 10. The HTO passage inside a bed in hot press machine

Fig. 11 shows the temperature in these four machines to be almost the same as in other machines. Thus, the flow rate is less, but the required temperature is satisfied for the heating process.

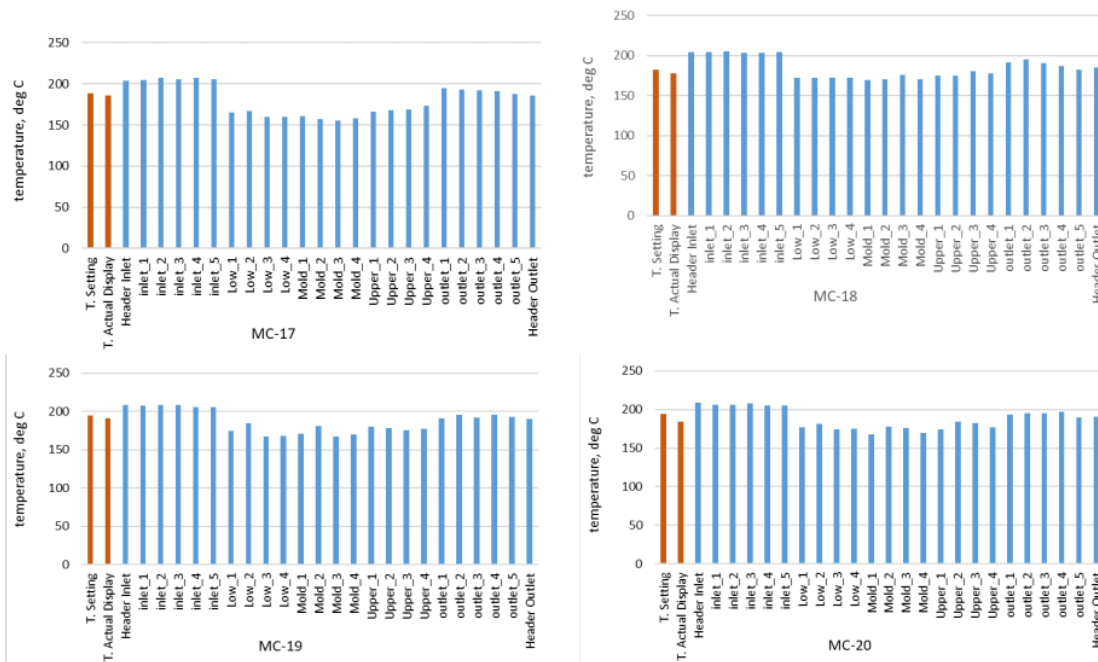


Fig. 11. The temperature measured in hot press machines MC-17 until MC-20

Fig. 11 shows that the surface temperature on the hot press machine MC-17 until MC-20 are like other machines even though HTO flows with smaller flow rate into the beds in MC-17 until MC-20. It is because the beds have more passes in those machines than others. More passes mean HTO distributes heat more evenly to the upper and lower beds.

The HTO flows in all layers with almost uniform rates as shown in Fig. 9. Yet, the surface temperature of the lower plate and mold at shaft 4 is still quite low compared to other shafts. Thus, the prediction of nonuniform flow rate is not proven.

3.4. Replacing the thermal insulation in the hot press machine

After weeks' observation, it was found that the reason for the lower temperature at shaft 4 was the heat loss to the hydraulic component below bed in shaft no. 4. The old asbestos was only 3 mm thick. The surface temperature at the bottom side of bed in shaft no. 4 was 150 – 157°C (shown as green line in Fig. 12) and temperature at below the asbestos insulation was 108°C (shown as orange line in Fig. 12). Reducing heat loss could reduce gas consumption.

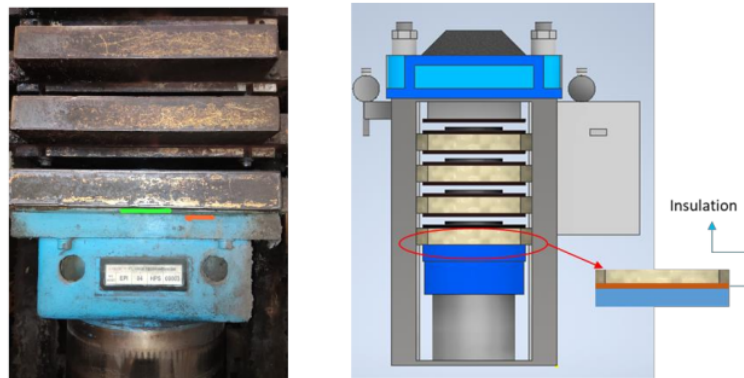


Fig. 12. The location of measuring temperature around the insulation, asbestos

The thickness of asbestos, the chosen thermal insulation, is as shown in Fig. 13. Calculating the heat loss from the bottom bed to the hydraulic component will give us an exponential curve in Fig. 13. The optimum thickness for asbestos to be installed under the lower bed in shaft no. 4 is 18 mm.

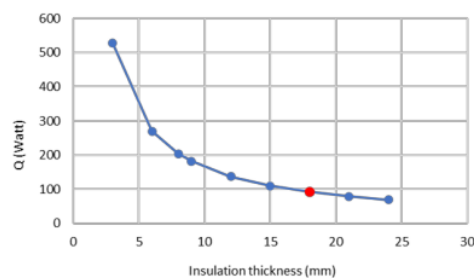


Fig. 13. The relation of heat loss vs thickness of the asbestos

As a beginning, the insulation was replaced only in machine MC-02 and MC-03. The old asbestos in both machines were already broken. The new asbestos inserted below the lower bed in shaft no. 4 is 18-mm thick as seen in Fig. 14.

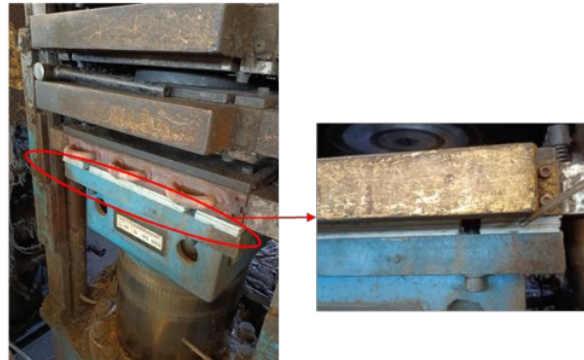


Fig. 14. The replacement of asbestos, the insulation in the hot press machine

3.4. The result of the replacement

Replacing the old and thin (3 mm thick) insulation with the new and thicker (18 mm thick) insulation gives improvement. The surface temperature at all upper & lower plates and molds in all shafts increases as shown in Fig. 15. The temperature in MC-03 is higher because the products need higher temperature.

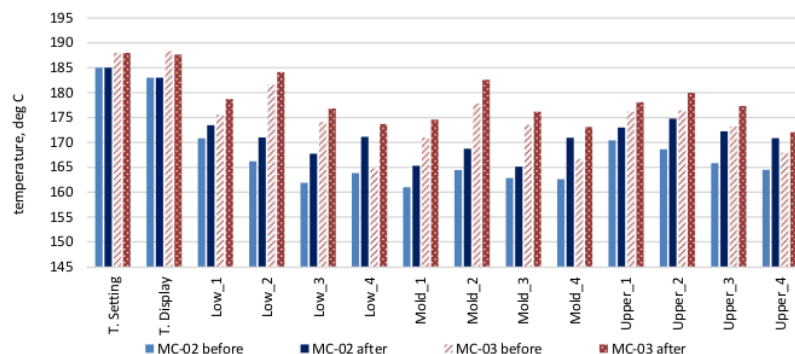


Fig. 15. The comparison of surface temperature before and after replacement in MC-02 and MC-03

Observing that the temperature increases and give excellent results, then PT. X decided to reduce the setting temperature at HTO heater from 220°C and 215°C. The results of lowering this setting is shown in Fig. 16. There are only 16 machines operating at the time data collected. This figure shows that the temperatures at surface of inlet headers are not affected as the HTO temperature from its source is reduced.

Reducing 5°C affect the natural gas consumption. When the HTO heater was set on 220°C, the gas consumption was around 20.3 MMBtu/day. But when the setting is reduced to 215°C, the gas consumption becomes around 18.8 MMBtu/day. Thus, the energy can be saved around 7.3% or 39 MMBtu/month (26 working days). According to the United States EPA (Environmental Protection Agency), this saving is equivalent to reducing 0.312 metric tons of CO₂ per month (24). This is a simple effort to use less energy to protect our environment.

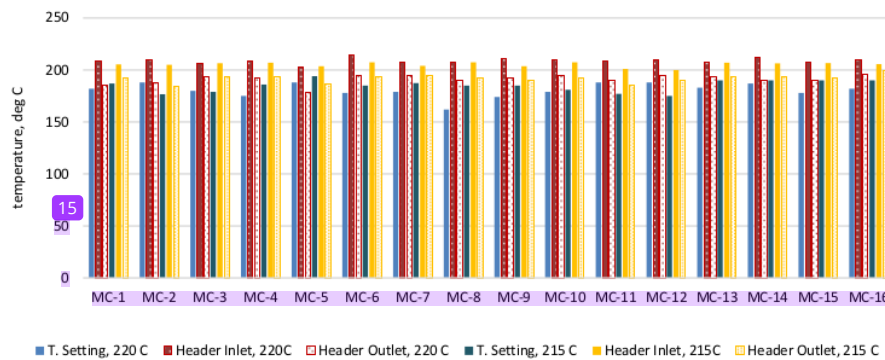


Fig. 16. The comparison of surface temperature at headers when the HTO heater set at 220°C and 215°C

4. Conclusions

The results from the assessment conducted in PT. X are (1) the thermal insulation in the piping system is good to prevent much heat loss to the surrounding, (2) the HTO flow rate fits the need for heating process, (3) some efforts to strive for energy sustainability in PT. X are (a) replacing the old and thin insulation to new and thicker asbestos and (b) lowering the setting temperature in HTO heater.

The achievement obtained is that the natural gas consumption is reduced around 7.3% or 39 MMBtu/month or equivalent to reducing 0.312 metric tons of CO₂ per month. This is a simple effort to use less energy to protect our environment.

For next research:

The thermal conductivity of the material will affect the material's ability to retain heat on the plate. Materials with high insulation capabilities will support operational costs, as well as protect components from premature damage to the system. Excessive heat can also cause thermal expansion of moving parts which can cause wear or tightness. Placing insulation sheets above and around the plate can improve the ability to control and maintain temperature, as well as to increase the uniformity and stability of the final product.

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