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Water Flow & Temperature Control to Increase Extraction Yield of Light-roasted Coffee Beans

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***Abstract*— Using light-roasted coffee beans for brewing espresso poses a general problem for pump-based espresso machines. Soluble in light-roasted coffee beans is more challenging to extract and requires a higher EY percentage because it has a relatively higher acidity level than dark-roasted coffee beans. The extraction range of 18% - 22% in light-roasted coffee beans for espresso brewing with an 8% - 12% TDS is qualitatively considered insufficient to produce espresso with a balanced taste. To improve the extraction ability of the espresso machine on coffee soluble. We design two features that hypothetically can solve the problem: Temperature Control Module to increase water temperature stability as a replacement for the thermostat, and Flow Control Module to regulate the speed of the vibration pump by adjusting the voltage resistance to reduce the water pressure/ flow rate used during the initial extraction at the preinfusion phase. Based on the results of trials using an espresso machine that has added temperature and flow control modules, there is an increase in the average percentage of extraction compared to the results of trials using stock machines; the average extraction percentage increased by 4.83 points. Qualitatively, this increase of %EY also significantly impacts the espresso taste, which tasted very sour and unbalanced, became relatively more balanced and comfortable to enjoy.**

***Index Terms*— espresso machine; extraction yield percentage; flow control; light-roasted coffee; preinfusion.**

I. The Problem

Coffee drinks are made by extracting the soluble from coffee beans to be dissolved in water. Several factors influence water's ability to extract the solubility in coffee beans, such as [1][2][3][4][5]:

- Water temperature.
- The ratio of the amount of water to coffee beans.
- Duration of extraction.
- Agitation.
- The particle size of coffee beans.
- The solubility of coffee beans.

The solubility of coffee beans received particular attention in this study. Dark-roasted coffee beans have a higher solubility than light-roasted coffee beans. Water more easily extract the soluble in dark-roasted coffee beans than light-roasted coffee beans. [6][7]

Espresso is a coffee drink with 8% - 12% Total Dissolved Solids (TDS) and 18% - 22% Extraction Yield (EY). With the composition of TDS and EY in these ranges, the extraction process that needs to be carried out by an espresso machine will be relatively more challenging than 1.15% - 1.35% TDS pour-over coffee drinks. Therefore, in brewing espresso, cafe generally uses dark-roasted coffee beans because of their relatively easy characteristics to be extracted to 18% - 22% EY with only a little water in 8% - 12% TDS. [8]

On the other hand, the trend of using light-roasted coffee beans continues to increase along with the current development of the coffee industry (the third wave of coffee), where the quality of green beans from the harvests of farmers is relatively better and can be classified as specialty coffee (based on Specialty Coffee Association standard):

- No more than five full defects in 300 grams of coffee.
- No primary defects.
- A maximum of 5% is tolerated or below the screen size indicated.
- Free of faults and stains.
- No Quakers are permitted.
- Moisture content is between 9-13%.

However, using light-roasted coffee beans for brewing espresso poses a general problem for pump-based espresso machines. Soluble in light-roasted coffee beans is more challenging to extract and requires a higher EY percentage because it has a relatively higher acidity level than dark-roasted coffee beans [9]. The extraction range of 18% - 22% in light-roasted coffee beans for espresso brewing with an 8% - 12% TDS is qualitatively considered insufficient to produce espresso with a balanced taste.

To achieve a higher %EY for light-roasted coffee beans, the extraction process that needs to be carried out by an espresso machine is also no longer able to follow the standard SCA (Specialty Coffee Association) method, where the extraction duration is limited to 30 seconds and the pressure used is 9 bar from start to finish. We have conducted trials to prove the research problem to be solved, using a standard Delonghi ECP33.21 espresso machine with the traditional SCA method and a Mazzer Super Jolly grinder with a 33M burrs set. The coffee used in the trial was light-roasted arabica from Kenya and roasted by Space Roastery Jogja. Based on the trial results in Table 1, the maximum %EY that can be achieved was 18.97%, with an average of 18.59% from 12 trials (the maximum number that the related machine can make in 1 water tank filling). In these conditions, with light-roasted coffee beans, the espresso taste was still relatively too sour and could not be appropriately enjoyed. The %EY obtained still needs to be increased to get a relatively more balanced espresso taste.

TABLE I. %EY PRELIMINARY TEST

Trial	Dose (gr)	Yield (gr)	Time (s)	%TDS	%EY
1	14	28.1	30	9.23	18.53
2	14	28.1	30	9.16	18.39
3	14	28.2	30	9.25	18.63
4	14	28.2	30	9.32	18.77
5	14	28	30	9.12	18.24
6	14	28	30	9.13	18.26
7	14	28	30	9.43	18.86
8	14	28.1	30	9.12	18.31
9	14	28.1	30	9.32	18.71
10	14	28	30	9.45	18.90
11	14	28	30	9.23	18.46
12	14	28.2	30	9.42	18.97
		Average			18.59

II. PRODUCT & LITERATURE REVIEW

A. Product Review

Entry-level espresso machines like the Delonghi have common components: water tank (45-53), vibration pump (79), overpressure valve (84), boiler (7,8,66,67), thermostat (4), and group-head valve. (9,10,14) [10]. Figure 1 shows the general components of the Delonghi espresso machine used by researchers in the test.

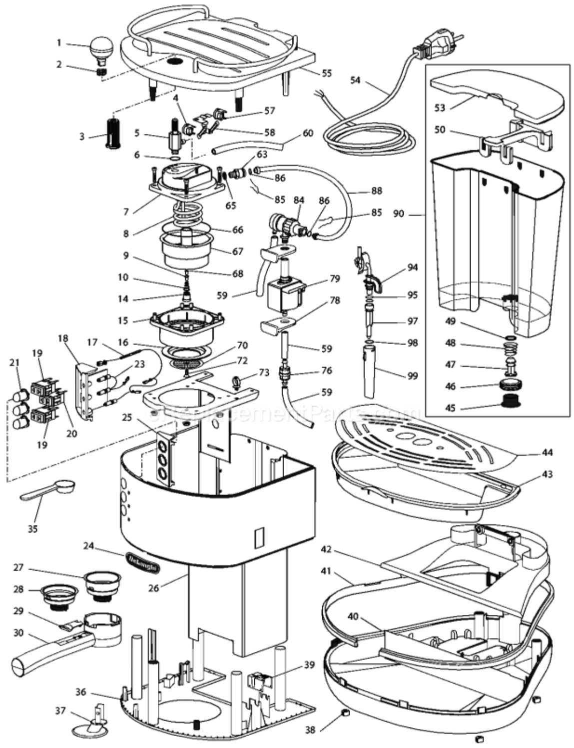

Fig. 1. Delonghi Components

Based on the researchers' observations, Figure 2 shows the structure of the circuit that composes the machine. When the engine is turned on, the boiler will immediately heat the water until it reaches the target temperature (105C) based on the thermostat attached to the outside of the boiler. The extraction process can be started by turning on the vibration pump that pumps water at room temperature from the water tank to the boiler. When the pressure in the boiler reaches 5bar, the group-head valve opens and lets water in the boiler come out for the extraction process. Between the water lines from the vibration pump and boiler, an overpressure valve will open when the pressure reaches 9bar to keep the extraction pressure from exceeding the limit.

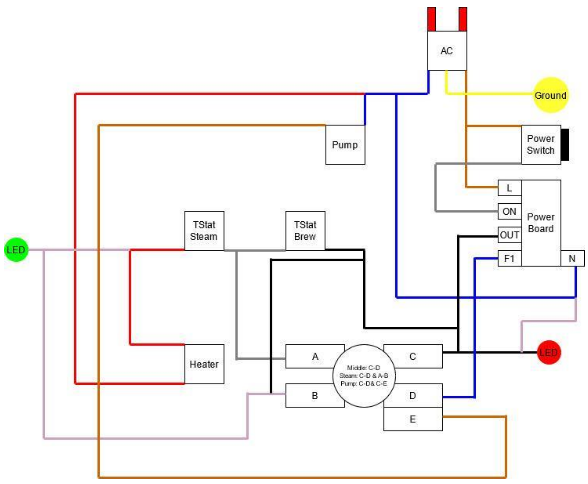

Fig. 2. Delonghi Wiring

B. Literature Review

Based on research [11], the water temperature used for the extraction process affects the ability of water to attract soluble contained in coffee bean particles. The higher the water temperature, the faster the extraction rate. If the soluble extraction is too low, the coffee will have a negative taste and disturbing acidity. However, if it is too high, some of the solubility, which has a negative taste, will also be extracted. Thus, to increase the extraction ability of an espresso machine properly, the temperature of the water used in the brewing process must be stable at the required number. Research [12] and [13] shows that the PID Control Algorithm can be used to maintain temperature stability well through its closed-loop design. PID Controller can maintain temperature stability better than a thermostat, which was only a relay based on the targeted temperature.

Research [14] shows dry coffee will have higher water resistance during the extraction process. While fully saturated coffee will be easier for water to pass through. Dry coffee flown by water with high pressure (9bar) has a higher possibility of channelling than fully saturated coffee. If channelling occurs, the extraction process in the basket will be uneven and have a lower extraction rate. Some parts of the coffee puck are highly extracted, while other parts don't. Reducing the coffee puck resistance and the risk of channelling can be done by flowing low-pressure/low flow rate water until the coffee is fully saturated before the primary extraction phase begin. This method is also called preinfusion. In research [15], the preinfusion phase can be done by controlling the speed of the vibration pump by adjusting the voltage given through the microcontroller.

C. Hypothesis

Based on the product and literature review related to the research problem, which is to improve the extraction ability of the espresso machine on coffee soluble. We will design two features that hypothetically can solve the problem:

1. Temperature Control Module with PID Controller: to increase water temperature stability as a replacement for the thermostat.
2. Flow Control Module: to regulate the speed of the vibration pump by adjusting the voltage resistance to reduce the water pressure/ flow rate used during the initial extraction at the preinfusion phase.

III. Solution & Testing Method

A. Solution

Figure 3 shows the new design of espresso machines that accommodate temperature control and flow control modules. Compared with Figure 2, the original design of a standard machine, there will be two main differences. The first difference lies in the two thermostats, which are no longer used and are replaced by a thermocouple probe with a PID Controller, which also functions as a Temperature Control module. The second difference was the addition of an AC Potentiometer to the circuit, which works as a Flow Control module to regulate the pump motor voltage of the espresso machine.

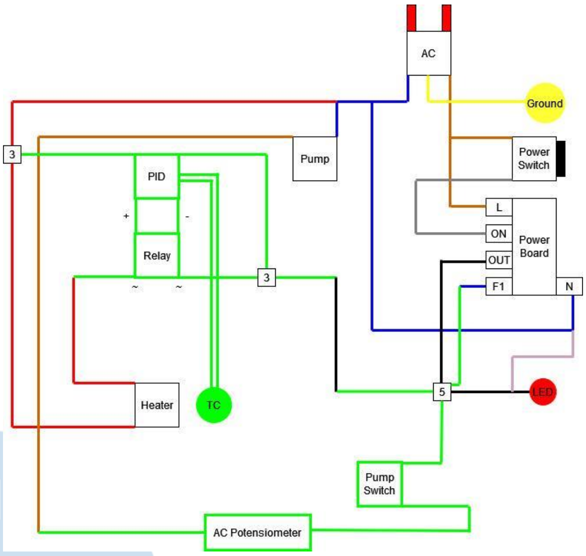

Fig. 3. New Wiring

In Figure 4 shows the internal parts of the espresso machine used. Researchers need to dismantle the inner frame that supports the boiler and pump motor to add the two modules.

Fig. 4. Boiler and Vibration Pump

In Figure 5 can be seen the final form of the machine that already has a temperature control and flow control module. The PID controller can regulate the water temperature in the boiler. Researchers used a water temperature of 115C in the boiler to produce a water temperature of 95C in the basket. The physical potentiometer knob can also adjust the motor speed on the vibration pump.

Fig. 5. The Final Build

Details of the removed parts:

- Steam wand and all of its connection pipes
- Brew/steam switch and all of its wiring
- Boiler's thermostat

Details of the added parts:

- PID controller and relay
- AC Potentiometer
- Two state switch
- 3D printed parts (front cover, module carrier, potentiometer's lever, switch bracket)

B. Testing Method

To measure the level of extraction, researchers used a refractometer from Atago [16], which can be seen in Figure 6; this tool can calculate the amount of soluble in coffee drinks. To measure the soluble coffee contained in espresso, we need to take a sample placed on the tool's lens to be measured. The measurement process occurs for a duration of 5 to 10 seconds. Ideally, the sample used has room temperature to maintain measurement consistency.

Fig. 6. Atago Refractometer

The extraction percentage calculation consists of the following steps:

- Measure the dose (D) of coffee used in grams.
- Measure the final espresso yield (Y) in grams.
- Measure the percentage of soluble coffee (TDS) successfully extracted at the final espresso yield using a refractometer.
- Measure the soluble gram (S) using the calculation: Y x TDS / 100
- Measure the percentage of extraction (%EY) that occurs by calculation: S / D x 100.

The test will begin by extracting 12 espressos (the maximum amount produced by the machine in 1 batch of water tanks) using the machine with added temperature control and flow control modules. The %EY will be measured on 12 espressos obtained, and the data will be compared with the previous preliminary testing data. Comparing the two data results will answer the research hypothesis of whether the two additional modules at the espresso machine can increase the machine's ability to extract soluble coffee in espresso drinks.

On the machine that has temperature and flow control modules, the brewing water temperature was set to 95C. As for the extraction profile, it uses the following steps:

- Do a pre-infusion for 20 seconds by setting the lowest water flow speed on the flow control module.
- Increase the speed of water flow through the flow control module until the end of the targeted extraction yield for 50 seconds. (The duration of 50 seconds was obtained from the calibration results based on the targeted yield amount. The calibration process was not described in detail in the report.).

IV. Result

The total data collection carried out by the researchers was 24 times for two test conditions, 12 times on a standard machine and 12 times on a machine that has added a temperature & flow control module. The amount of data collection was based on the maximum limit of espresso that both machines can produce in a fully filled water tank. Testing was based on conditions that were attempted to be close to the actual use situation.

The grind setting used in the test was based on the results of the researcher's dial with the highest possible %EY value target for each machine. The standard machine has a grind size that was relatively coarser than the modified machine. When the grind size on the standard machine was forced to be finer, the %EY did not increase. Instead, it decreases due to channelling in the puck.

The dose of coffee used in each test was 14 grams and was targeted to produce approximately 28 grams of espresso. The doses can be adjusted precisely but not with yield. It was challenging to ensure the yield would always be the same in every test due to the limitations of machines that still need to run and shut the pump manually.

Based on the test results, which can be seen in Table 2, the maximum %EY that can be achieved was 23.62%, with an average of 23.43% from 12 trials. Qualitatively, the espresso produced was more balanced than from the stock machine in the preliminary experiment. The intensity of the sourness in the under-extracted espresso has significantly reduced.

TABLE II. %EY Final Test

Trial	Dose (gr)	Yield (gr)	Time (s)	%TDS	%EY
1	14	28.2	50	11.66	23.49
2	14	28.1	50	11.68	23.44
3	14	28.2	50	11.54	23.24
4	14	28	50	11.73	23.46
5	14	28.1	50	11.72	23.52
6	14	28.1	50	11.63	23.34
7	14	28.1	50	11.62	23.32
8	14	28	50	11.69	23.38
9	14	28	50	11.81	23.62
10	14	28.2	50	11.64	23.45
11	14	28	50	11.72	23.44
12	14	28	50	11.75	23.50
Average					23.43

V. Conclusion

Based on the results of trials using an espresso machine that has added temperature control and flow control modules, there was an increase in the average percentage of extraction compared to the results of trials using stock machines; the average extraction percentage increased by 4.83 points. Qualitatively, this increase of %EY also significantly impacted the espresso taste, which tasted very sour and unbalanced, became relatively more balanced and comfortable to enjoy.

The research hypothesis was already answered, as shown in Figure 7, that adding temperature control and flow control modules on the Delonghi ECP33.21 espresso machine can increase the machine's ability to extract solubles from light roast coffee beans.

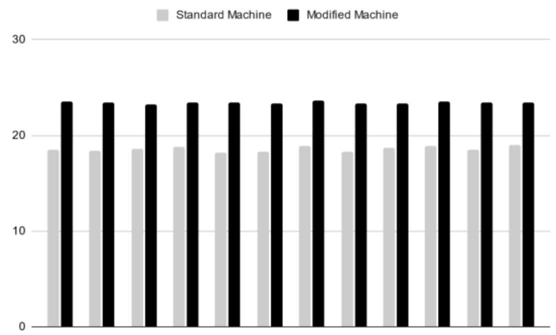

Fig. 7. %EY Comparison

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