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Development of Low-Cost Electrospinning to Fabricate Structured Nanofiber for Biomedical Designs with Manageable Flowrate and Voltage

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ABSTRACT Electrospinning is the most popular method that uses in nanofiber production. However, the budget to purchase this tool in the market is expensive. This article aims to report on how to build electrospinning on a lesser budget. There are three main components in electrospinning that will be broken down regarding how to build it. First, the syringe pump creates machinery to push the liquid in the syringe creating a Taylor cone affected by high voltage. Second, a high voltage power supply occurs electrostatic force. Third, the collector gathers nanofiber products. This machine has cost Rp 3.168.822 or $220,26. This number is less than the shop production or the previous report to create low-cost electrospinning. To make sure that this method successfully creates nanofiber. Scanning Electron Microscopy (SEM) is conducted and the result shows that the fiber size is 719±0,06 nanometers. Moreover, the flow rate and the voltage also have been assessed resulting that they are in a controllable manner by showing a linear profile. In this article, the budget is shared to declare that this electrospinning is more affordable. Hopefully, this report could help researchers who intend to build electrospinning at the lab scale to develop their research in nanofiber products with less cost.

INDEX TERMS Low-Cost, Electrospinning, Nanofiber

I. INTRODUCTION

Electrospinning is the most successful technique to produce nanofibers. It is because of not only the huge number of publications produced by this tool but also because this method is relatively easy to make. Electrospinning implements the principle of electrostatic voltage to stretch the liquid and elongates it to become fibers[1]. The fabrication process using electrospinning has significant advantages over other types of methods such as self-assembly [2], solvent casting[3] and gas foaming[4]. This tool can combine the desired material to produce the required material characteristics.

Nonetheless, it has the appropriate performance to apply for biomedical purposes. The cheapest electrospinning price for research according to NanoFMG is 17,000 USD[5] or around Rp. 250,000,000.00. Meanwhile, for mass production for company requirements, the cheapest price is 2.5 billion rupiahs or 170.500$. On the other side, some universities testified assembling their electrospinning and making modifications according to their research needs [6][7]. Based on the reports, it can be claimed that building individual electrospinning devices can save up to 95% of the budget.

Electrospinning applied electrostatic force to create nanofiber material structure. This electro-physical phenomenon elongates and thus stretches the solution from the tip of the syringe to the collector helped by evaporation events making the fiber getting thinner. The parameters affected by this method could be classified into three categories which are set up parameters, fluid parameters, and environmental parameters. It has been reported that the fluid parameter is the most influenced factor considered for viscosity, conductivity, and surface tension[8]. In the assessment of the result, beads are usually generated in this method. Jet axisymmetric instabilities the cause of this discrepancy[9]. It should be noted that flow rate and voltage should be in manageable manner to attain the result consistency.

The building of low-cost electrospinning has been published as a biomedical engineering practicum tool for studying biomaterials science. The manufacturing stages consist specifically; of designing 3D computer-aided images, making a cabinet from acrylic material, building a collector, and fabricating Polyvinyl Alcohol (PVA) as a material to determine whether nanofiber can be fabricated [5]. Another study presented a standard electrospinning system consisting of three constructed parts, a hand-constructed electrical power supply to provide a voltage source direct current (DC), a low-cost three-dimensional (3D) printed syringe pump, and handmade collectors [10].

This article is imposed to report how to build electrospinning on a lesser budget with manageable flow rate and voltage. Building syringe pump, high voltage power supply, and the collector are elaborated step by step to get a better understanding of this tool. Moreover, the result of fabrication is captured by Scanning Electron Microscope (SEM) to ensure that the product is in the nanometer dimension (<1000nm)[11]. The flow rate and the voltage are also assessed to see if they are stable. Lastly, the budget of this device is shared to perceive that this tool is more affordable.

Nanofiber is suitable for biomedical experiments especially in tissue engineering[12] because the structure mimics extracellular matrix and the material can be engineered to perform biocompatibility in a cell environment. It has been reported that nanofiber is used as tissue-engineered scaffolds for various tissues such as bone[13], cartilage[14], cardiovascular[15], and skin tissues[16].

II. MATERIAL AND METHODS

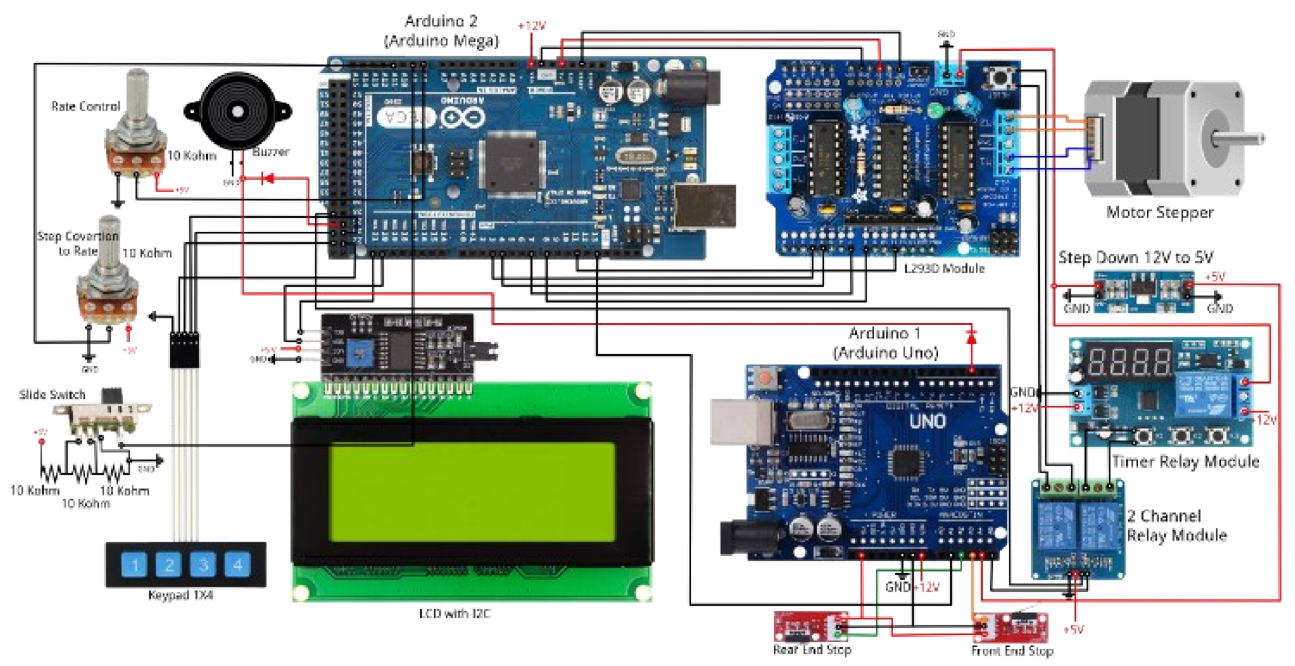

FIGURE 1. Schematic Design of The Syringe Pump

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Building electrospinning consists of three main parts which are (1) Building syringe pump machinery, (2) Establishing a high voltage power supply, and (3) Constructing a collector.

A. BUILDING THE SYRINGE PUMP

The syringe pump is one of the most important elements in electrospinning machinery. It provides the force applied to solution which creates Tylor cone in tip of the needle. Taylor cone is the structure usually generated by a tube nozzle when it is required by a high potential[17].

This syringe pump is built by the Adafruit Motor Shield-v1 as a stepper motor driver because it has the advantage of being able to control stepper motors (unipolar or bipolar) with single coil, double coil, interleaved, or micro-stepping modes[18]. Single or double means the number of coils that are activated at once for higher torque and interleave means that it alternates between single or double to get twice the resolution, but it has half the speed. Micro stepping is a method that is implemented where the coils are PWM'd to create smooth motion between steps[19]. It uses the L293D chipset which can provide a current of 0.6A per bridge (1.2A peak) with 4.5V to 25V thermal shutdown protection making it safer. It has also a terminal block for connecting separate external power with a stepper motor logic block. This approach could control the stepper motor with constant speed. It should be noted that the Adafruit Motor Shield-v1 has a drawback so that it cannot interrupt the program when running the stepper motor. Consequently, another Arduino is needed to interrupt as a safety or system checking. The elements that construct this structure schematically can be seen in Figure 1.

B. ESTABLISHING THE HIGH VOLTAGE POWER SUPPLY

A high voltage power supply generates the electrostatic forces between tip and collector[20]. At the top of the needle tip, the solution is grabbed by surface tension and on the other hand, the repulsion elongates the solution to become the fibers[7]. To ensure this phenomenon occurs in stable conditions, the high voltage power supply needs to be engineered reconsolidating the requirement. In this work, the high voltage supply is adapted from a series-configuration Mazzilli ZVS flyback converter[21]. This approach report could generate a high voltage that able to generate nanofiber. The detail of schematic diagram regarding the high voltage power supply with its electronic components could be seen respectively in Figure 2 as PWM controller, Figure 3 as an analog output to the microcontroller, Figure 4 as Mazzili ZVS flyback converter, and Figure 5 as measurement circuit uses resistor R1(0.982867 Mega Ohm) with R2 (974.7 Mega Ohm) smd 1206.

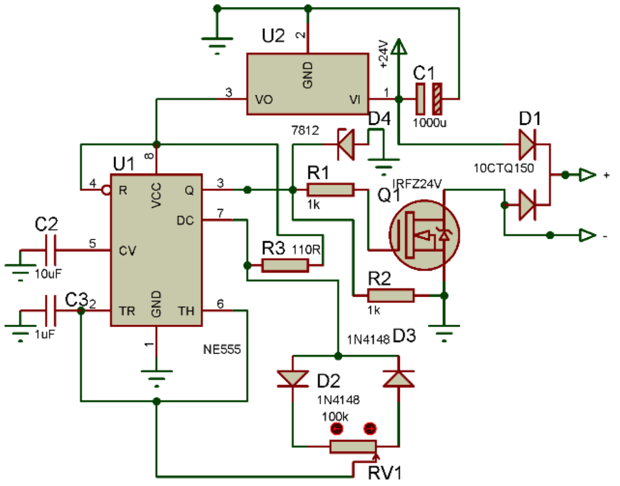

FIGURE 2. PWM Controller

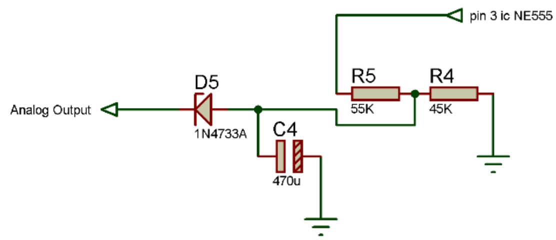

FIGURE 3. Analog Output to Microcontroller

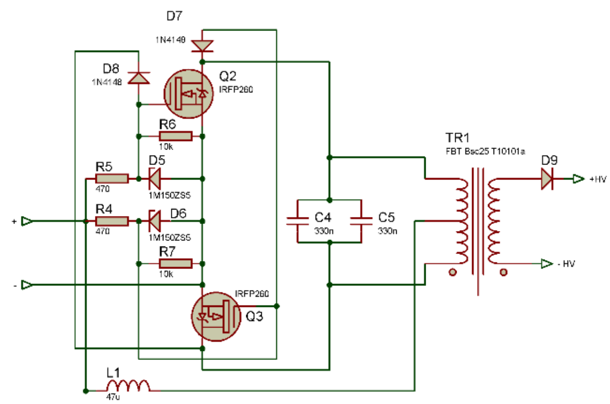

FIGURE 4. Mazzili ZVS Flyback Converter

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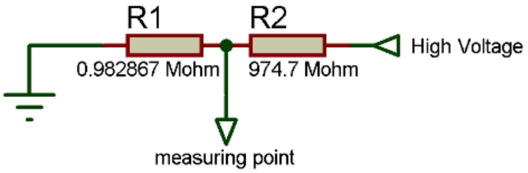

FIGURE 5. Measurement Circuit

C. CONSTRUCTING THE COLLECTOR

It has been developed various approaches to gain the quality of the product in nanofiber fabrication by the engineered collector. In this low-cost scenario, the flat metal is used as the collector. This simple structure still can accumulate the fibers and is easy to manage for observation by adding a coverslip of the microscope. At the end of the process, the fibers will be peeled off and ready to follow the next steps. Figure 6 shows the simple collector applied in this low-cost electrospinning.

FIGURE 6. The Simple Collector Made by Flat Plate

The collector is an essential component in electrospinning machinery. Different type collector needs to be engineered to answer the specific objective[22]. In this report the collector does not need any complex structure or electrical instrumentation. The collector is the compartment that collects the fibers after they are stretched, elongated, and evaporated. It needs to connect to the negative charge of the high voltage power supply. The effect of the geometry collector reported critical to nanofiber distribution within the 3D scaffold refers to length-to-width ratio and inclination angle[23].

III. RESULTS

A. ELECTROSPINNING ASSEMBLED FROM THREE MAIN COMPONENTS

Electrospinning has been successfully constructed by compiling three main components. Figure 7 shows the electrospinning machine as a whole structure.

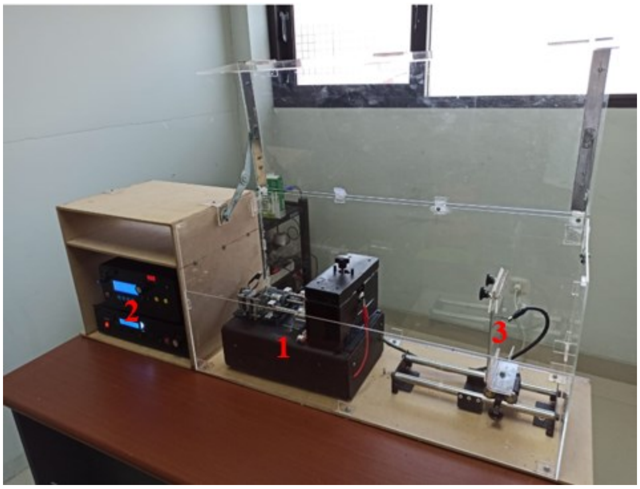

FIGURE 7. The Electrospinning Machine

In Figure 7, the syringe pump is indicated by number 1, the high voltage power supply is showed by number 2, and the collector is revealed in number 3 are ready to run the fabrication of nanofiber material.

The syringe pump is placed in the middle of the system. This component has a vital function in managing significant parameters such as flow rate that is affected by viscosity. This machine still could manage the various viscosity to hold the Tylor Cone. The collector is placed next to the syringe pump. In this construction, the slider is the key to varying the distance between tip and collector. This variable is reported become a significant role in the electrospinning process[24][25].

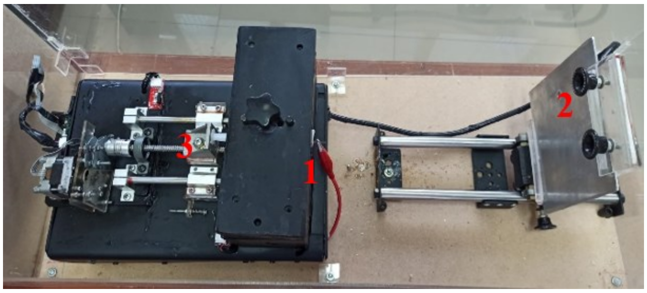

FIGURE 8. Syringe Pump and Collector System

The high voltage power supply is managed places in the box. This is necessary to minimize the risk of electrical hazards. This component could rise a voltage until 20kV. It is high enough to establish an electrostatic force to create nanofiber than 15kV[26][27].

FIGURE 9. Syringe Pump and High Voltage Power Supply Setting Management

Figure 9 shows the assembly of the syringe pump and high voltage power supply (1) including: (A) the timer of process, (B) flow rate setting, (C) timer setting, (D) timer mode, (E) maximum rate control, (F) restart setting option, (G) syringe pump LCD, (H) motion setting: (a) backward, (b) stop/rest, (c) run, (d) forward., (I) high voltage power supply display, (J) AC power button, (K) high voltage power button, (L) high voltage setting. Meanwhile, Figure 9 (2) shows a syringe pump LCD, and Figure 9 (3) provides a high voltage power supply screen.

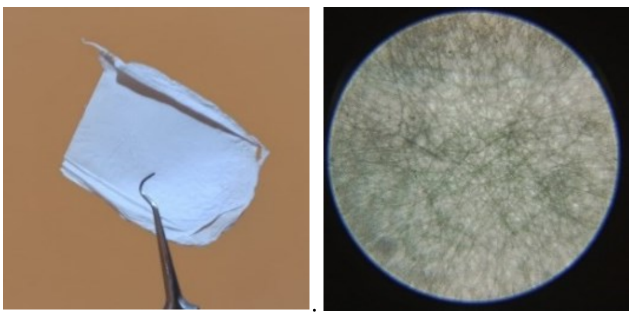

FIGURE 10. Nanofiber actual sample and it is under light microscope investigation

B. NANOFIBERS OBSERVED IN ELECTROSPINNING MANUFACTURE

Ensuring the low-cost electrospinning could make the nanofiber. The study regarding the product of fabrication was conducted. After the process, the nanofiber that is attached to the collector is observed by microscopic with 500x magnification. This is important as a preliminary investigation to make sure that fiber is created during the process. Figure 10 compares the investigation under light microscopic and actual samples.

After the fiber has already been examined the following step is to assess the dimension. The terminology for nanofiber is when the fiber is reach under 1000 nanometers[11].

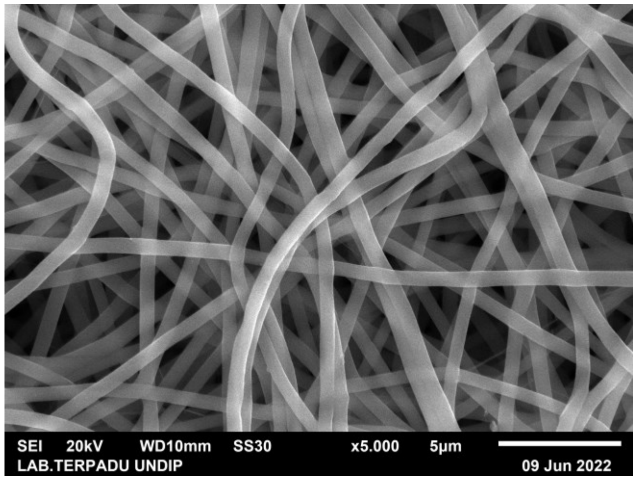

FIGURE 11. Nanofiber captured under scanning electron microscopy

Based on Figure 11 it could be seen that nanofiber is exposed clearly. The white line at the left bottom of the figure indicates the scale that refers to 5 µm. By using imageJ software it could be measured that the nanofiber has an average size 719±0,06 nanometers. It is because the size is under 500 nanometers, that it could be claimed that this electrospinning successfully produces nanofiber.

C. FLOWRATE AND VOLTAGE EXAMINED IN STABLE PROFILE

The crucial aspects of this electrospinning are to provide stable voltage and a steady flow rate. This is important because this parameter is suspected to be the reason for the defect of electrospinning. If the voltage is unstable the electrostatic force that is generated in this system could make the non-uniform feature[28][29]. Furthermore, the steady flow rate is to make sure that the elongated process is stable creating consistent dimensions. The result of assessing the profile of voltage and flowrate could be seen in Figure 12.

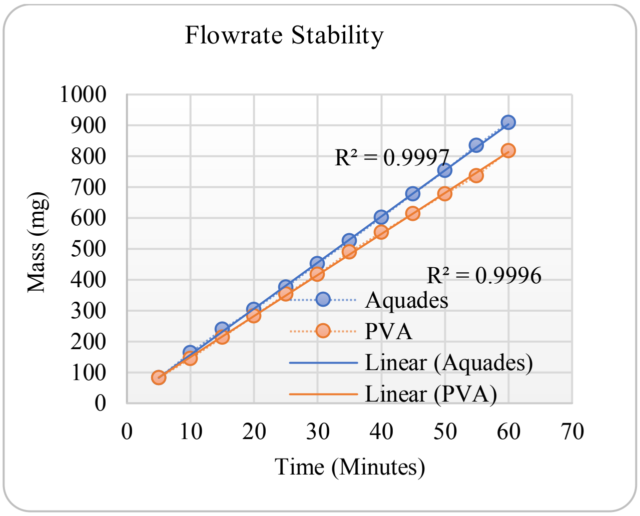

FIGURE 12. Linearity flowrate indicates that flowrate is stable

Moreover, to assess the stability of high voltage, the input and output value has been plotted to see the profile. Based on Figure 13 it could be seen that the R number is 0,09986. This value interprets that the profile is linear enough to justify that this high voltage system is robust.

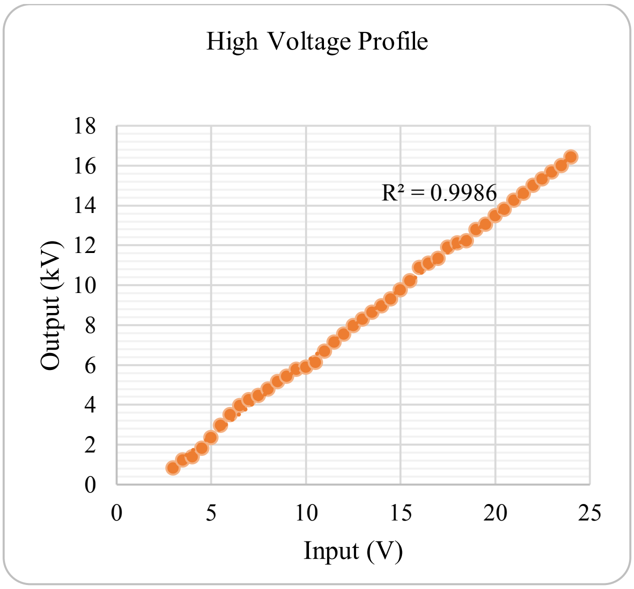

FIGURE 13. Output vs input linearity intended that high voltage is the robust condition

D. ELECTROSPINNING COST REPORTED IN LESSER PRICE

The total cost to build this electrospinning is provided in Table 1. This value is less expensive than the previous report and this scenario could be adopted to develop research in nanofiber production.

TABLE 1
Total Cost to Build Electrospinning

No	Name of Components	Budget (Rupiah-Indonesia)/ Dollar -USA
1	Machine Controller	Rp 769.600/ $ 53,49
2	Syringe Pump	Rp 841.972/ $58,52
3	Box Acrylic-based	Rp 398.500/$27.70
4	High Voltage Powe Supply	Rp 968.750/$67,34
5	Collector	Rp 190.000/$13,21
	Total	Rp 3.168.822/$220,26

Based on Table 1 the cost of electrospinning is less than the previous report[5]. Electrospinning could be an asset for the development of advanced materials. By developing this machinery, the collaborative research opportunities are more open related to the engineering of nano-sized materials, especially for engineering human tissue.

IV. DISCUSSION

To build electrospinning instrument the researcher could adapt this method step by step. It has been written in detail the component and the design of this machinery. Electrospinning with lesser cost has been successfully constructed assembled by three components which are syringe pump, high voltage supply, and collector (Figure 7 and 8). This tool could modulate crucial parameters such as flow rate and voltage. It could be seen in Figure 9 this development providing various scenario to deal with characteristic of electrospinning research with its setting management. This approach could support modifying the speed of flow rate and the power of voltage.

Based on the investigation it could be seen that these parameters observably could be achieved in manageable profile (Figure 12 and 13). This is essential achievement considering that these two parameters affect the result of fabrication regarding bead generation.

Regarding cost perspective, it has been shared the budget of this product in Table 1. This tool has got lesser price than previously report in article that mentioned in introduction section. Hopefully, this article could be use as references to help researcher that has intention to build the electrospinning machine in their laboratory but has a challenge related to the financial issue. The limitation of this method is the conventional collector It could be seen that the fiber result is non-woven condition. This type of nanofiber structure has been confirm using SEM (Figure 11). Developing collector in different design could be solution that solve this challenge[7].

V. CONCLUSION

Based on the result, it could be concluded that low-cost electrospinning has successfully been built consisting of three main components which are a syringe pump, high voltage power supply, and collector. Nanofiber structured has been by observation under Scanning Electron Microscopy whose value is 719±0,06 nanometers. The linearity profile in flow rate and voltage indicates that this tool is robust. Furthermore, the reporting budget shows that this approach is a lesser cost than the previous report. In the future, the optimization of influenced parameters needs to be conducted to see the characters from a more holistic perspective.

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