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# A STUDY OF COMBUSTION IMPROVEMENT FOR FLAME PROPAGATION IN A TUBE BY USING COMBINATION FLOW AND MIXTURE INJECTION

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***Abstract***

*Experiments on combustion of lean mixtures in the vicinity of flammability limit have acquired importance from the viewpoint of development of new kinds of combustion system with low fuel consumption and low emissions. It is well known that the combustion characteristics near the lean limit are instability and low heat release rate. Therefore, it is necessary to improve the combustion behaviour by using several techniques.*

*Experiments have been carried out to examine the influence of combination flow and mixture injection on flame behaviour and flame propagation speed for lean premixed propane-air mixtures in a combustion tube.*

*The mail conclusions are as follows: 1) The Average flame speed with the swirl flow is remarkably increased as compared with the case of laminar flow. 2) The Average flame speed by using the combination flow is bigger than that of the swirl flow. 3) By changing the combination flow intensity, it is possible to control the flame speed. 4) The flame speed by using injection of premixed mixture to flame front is higher than that of laminar flame speed without the mixture injection. 5) The most suitable conditions exit for combustion improvement near the flammability limit by using the mixture injection.*

***Keywords:*** *combustion improvement, combination flow, mixture injection*

## 1. Introduction

The recent emphasis on emission control has prompted the development of new type combusters and internal combustion engines, which invariably deal with very lean hydrocarbon-air mixtures. However, accurate data on combustion characteristics of such mixtures are scarce in literature owing to difficulties inherent in conventional measuring technique [1-3]. Furthermore, the determination of combustion improvement for extremely lean mixtures is very important for safety and combustion engineering.

As the first step in this study, experiments have been carried out to examine the influence of combination flow and mixture injection on flame behaviour and flame propagation speed for lean premixed propane-air mixtures in a combustion tube.

## 2. Experimental Apparatus and Procedure

Figure 1 shows the experimental set up employed in this study. It consists of a combustion tube, an ignition system, a digital video camera, a recorder and a mixture tube. The fuel-air mixtures in a combustion tube are ignited at one end by a small heated nichrome wire and immediately after ignition, that end is opened to atmosphere by operating the electromagnetic valve. The far end is kept closed until the end of combustion process. The combustion tube of 70 mm in internal diameter and 770 mm in length is mounted horizontally inside the frame of experimental device. The behaviour of flame propagation is observed by the high-speed digital video camera.

The combustion tube is equipped a turbulence generater (blade: 7 blade type and 11 blade type (Fig. 2 (a), (b)) and plate with hole(center hole type 30 mm and 20 mm (Fig. 2 (c), (d)) and two or three holes type (Fig. 2 (e), (f)), the distance from blade to plate with hole are changeable from 150 to 250 mm. The blade located at the position 250 mm from the ignition point in the combustion tube. Fourthermore, the combustion tube can possible to change the mixture injection type(premixed mixture injecte to flame front from the combustion tube wall). The fuel used is propene with purity of 99.0%. The data of 25 tests for each experimental condition were averaged arithmetically, the standerd deviation being less than 5%. In these experiments, a mixture of 79% nitrogen and 21% oxygen by volume is used as a substitute for air by using flow meter and the equivalence ratio is defined as the fuel-air ratio divided the by the fuel-air ratio for a stoichiometric mixture. Experiments were conducted at initial temperature of 25°C and initial pressure of 0.1 MPa.

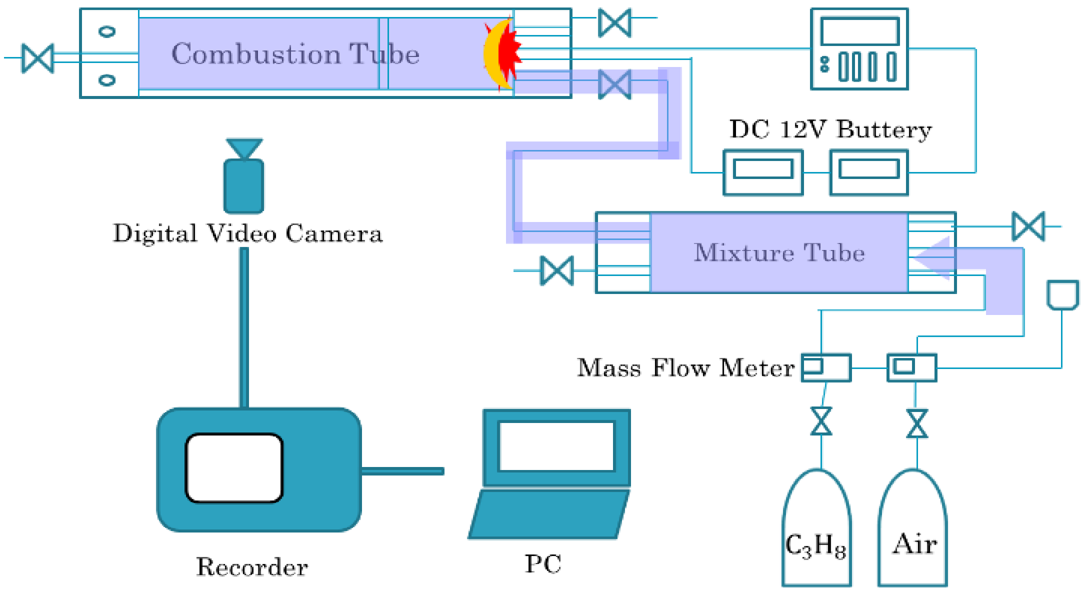
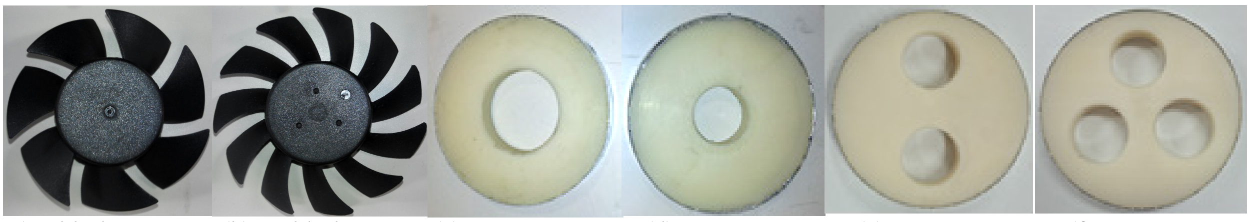



*Fig. 1. Experimental device*



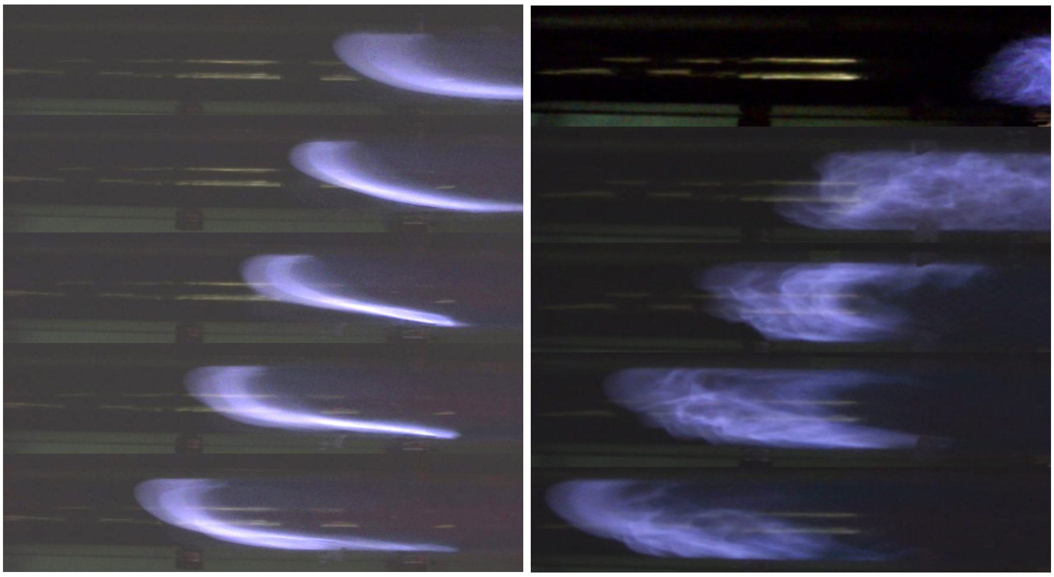
| | | | | | |
|---|---|---|---|---|---|
| *a) 7 blades Ratio of blade aria: 85%* | *(b) 11 blade Ratio of blade aria: 71%* | *(c) 30 mm Centre hole type* | *(d) 20 mm Centre hole type* | *(e) 20 mm Two holes type* | *(f) 20 mm Three holes type* |

*Fig. 2. Experimental blade and plate with hole*

## 3. Experimental Results and Discussion

### 3.1 Combination flow

Typical examples of direct digital colour photographs of the flame propagation near the lean limit of inflammability of propane-air mixtures with laminar flow and swirl flow by using the plate of 7 blades type are shown in Fig. 3, respectively. The plate of 7 blades type is equipped the 250 mm position from the ignition point in the combustion tube. As seen from this figure, when the laminar flame propagation (quiescent mixture), a smooth propagation is established through the combustion process near the lean flammability limit. On the other hand when the swirl flow by using plate of 7 blades type in the combustion tube, the flame surface is irregular through the combustion process.



(a) Laminar flow (b) Swirl flow (7 blades)

Fig. 3. Flame shape (Propane-air $\varphi$ =0.55)

Figure 4 shows the average flame speed of propane-air mixtures against equivalence ratio as a function of swirl flow (7 blades and 11 blades) in the combustion tube. As seen from this figure, it can be seen that the average flame speed with swirl flow are bigger than that of laminar flow. Furthermore, the average flame speed by using the plate of 7 blades are bigger than that of average flame speed by using the plate of 11 blades at any equivalence ratio. This fact indicated that it is possible to control the average flame speed near the lean flammability limit of propane-air mixtures by using the swirl flow. Furthermore, the increasing ratio depends on the number of blade.

Figure 5 shows the average flame speed of propane-air mixtures against equivalence ratio for combination flow. Where the combination flow generated by putting the plate of 7 blades and one hole plate in the combustion tube. The distance of both plates is 200 mm. From this figure it can be seen that the average flame speed by using combination flow are bigger than that of the laminar flow (one hole plate) and swirl flow (7 blades) at any equivalence ratio near the flammability limit. This fact indicated that the combination flow are more effective to increase the average flame speed near the lean flammability limits than that of the axis flow(one hole plate) and swirl flow. It is causes by the increasing the area of flame front by using the combination flow.

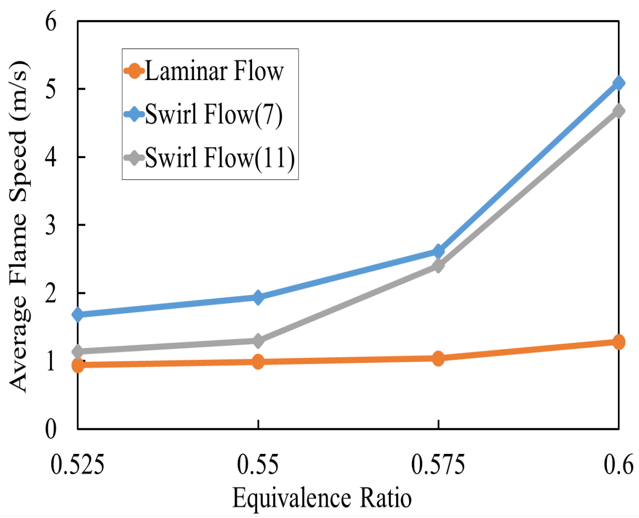



Fig. 4. Aberage flame speed with swirl flow

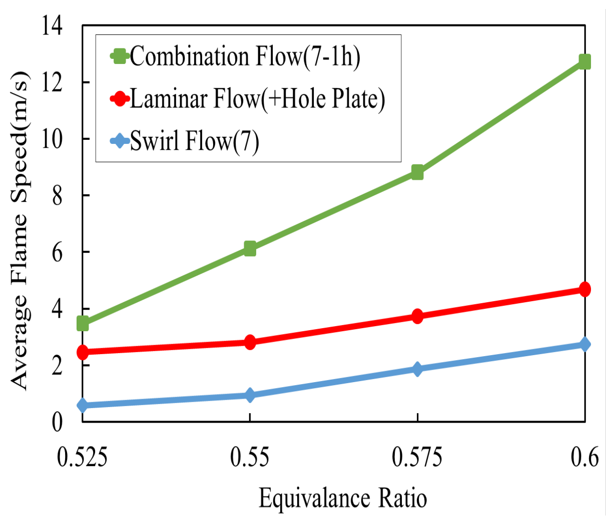



Fig. 5. Aberage flame speed with combination flow

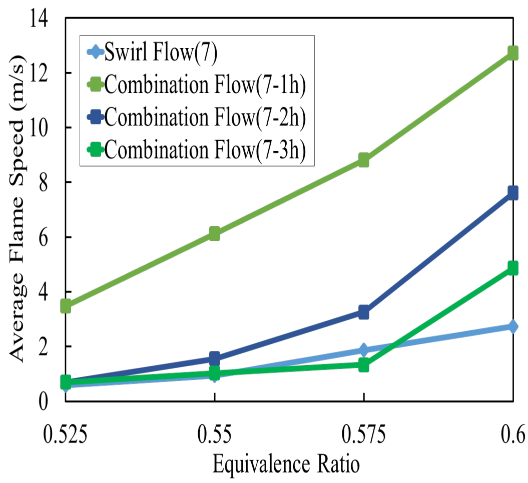



Fig. 6. Aberage flame speed with combination flow (effects of hole number)

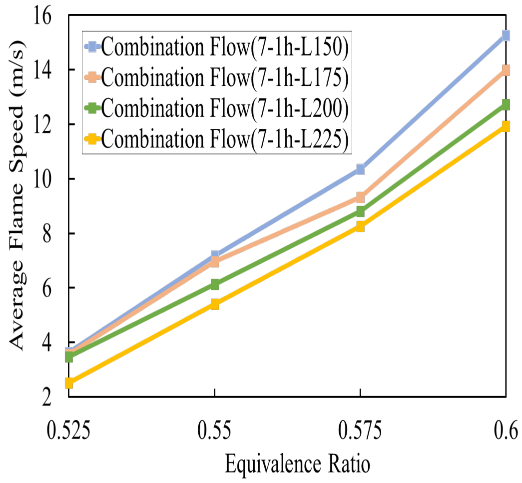



Fig. 7. Aberage flame speed with combination flow (effects of combination flow intensity)

Figure 6 shows the average flame speed against the equivalence ratio as a function of number of hole under combination flow, where: Swirl flow (7): plate of 7 blade, Laminar flow(+Hole Plate):plate of one hole, Combination flow (7-1h): plate of 7 blade and plate of one hole

From this figure the maximum average flame speed obtained by using the combination flow (7-1h) at any equivalence ratio near the lean flammbility limit. This fact indicated that the combination flow of 7-1h type is effective the increasing the average flame speed. It is causes by the influence of increasing the mixture injected speed near the center axis, it is necessity to discuss the effect of the combination flow intensity near the lean flammability limit.

Figure 7 shows the average flame speed against the equibalence ratio as a function of combination flow intensity. In this experimet, combination flow intensity can contorol to change the distance from the plate of blade to the plate of hole. From this figure it can be seen that the average flame speed monotonically increases with decreasing the distance of both plates at any equivalence ratio. It is interesting fact that the average flame speed near the flammaility limit can easy to control by using the simple combination flow.

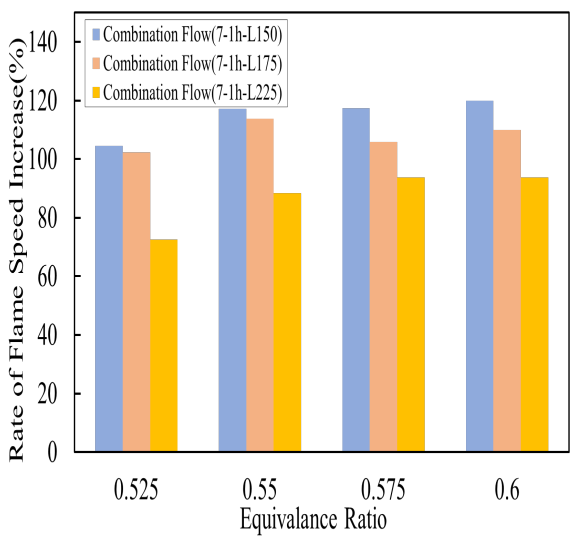



Fig. 8. Rate of flame speed increase

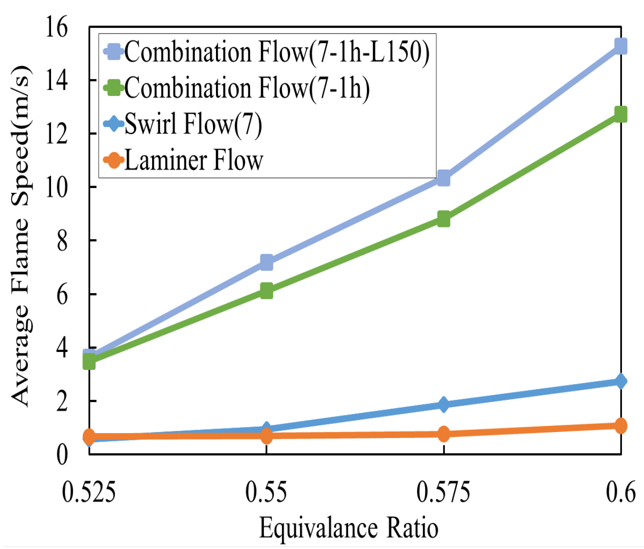
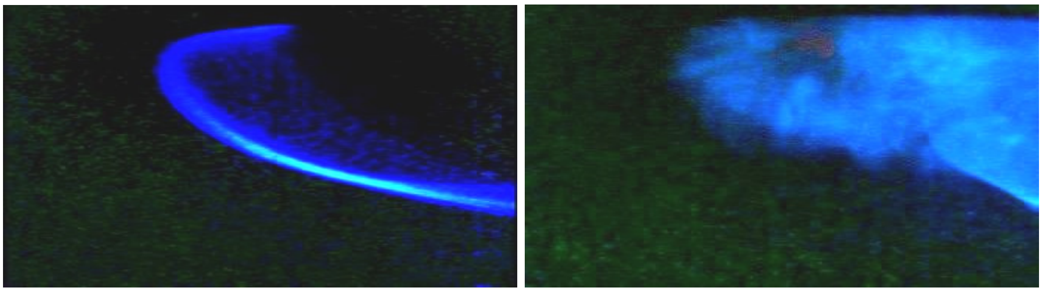



Fig. 9. Average flame speed (Comparison)

Figure 8 shows the rate of flame speed increase against the equivalence ratio as a function of combination flow intensity. The rates of flame speed increase are calculated from the average flame speed under each combination flow divided by the standard average flame speed of combination flow (combination flow7-1h-L175: φ= 0.525). From this figure, the rate of flame speed increase decreases with increasing the distance of both plate at any equivalence ratio.

Figure 9 shows the average flame speed against the equivalence ratio for comparison of the kind of flow. From the figure, it can be seen that the average flame speed of combination flow are bigger at any equivalence ratio than that of maximum average speed with swirl flow. Furthermore, the increasing rate of average flame speed is bigger than that of swirl flow.

### 3.2 Mixtures injection



*(a) Before mixture injection* *(b) After mixture injection from tube wall to flame front*

*Fig. 10. Flame shape (Propane-air φ =0.60)*

Typical examples of direct digital colour photographs of the flame propagation near the lean limit of flammability of propane-air mixtures without mixture injection and with mixture injection are shown in Fig. 10, respectively. The injection system of mixture is equipped the 450 mm position from the ignition point at the combustion tube wall. As seen from this figure, the flame shape before the mixture injection is a smooth and the flame shape after the mixture injection, the flame front is irregular by the mixture injection.

Figure 11 shows the flame speed against equivalence ratio as a function of equivalence ratio of the injection mixture. From this figure it can be seen that the flame speed by using the mixture injection are bigger than that of the without the mixture injection. Furthermore, the highest values are obtained with the equivalence ratio of 0.575 without laminar flow. This fact indicated that the most suitable conditions exit for combustion improvement near the flammability limit by using the mixture injection.

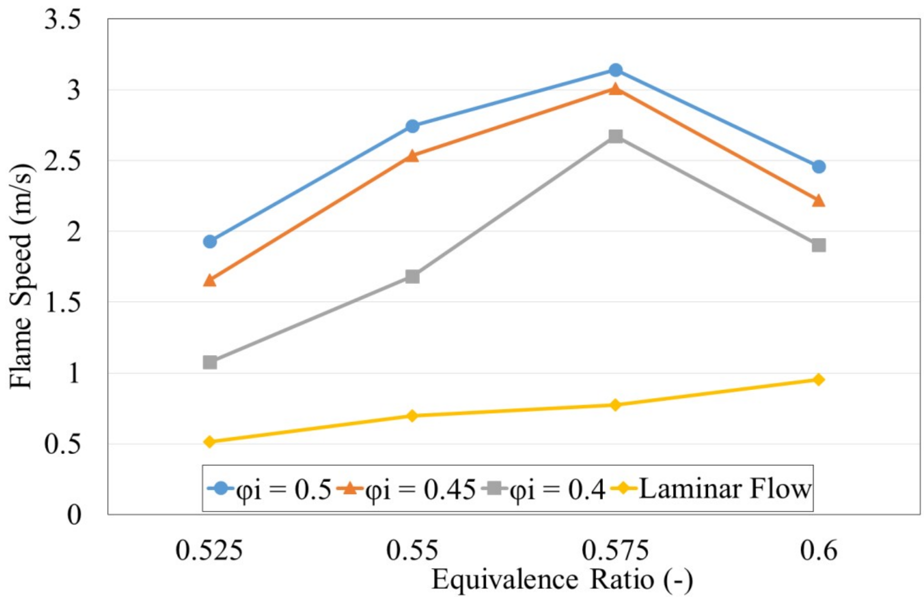



*Fig. 11. Flame speed with mixture injection*

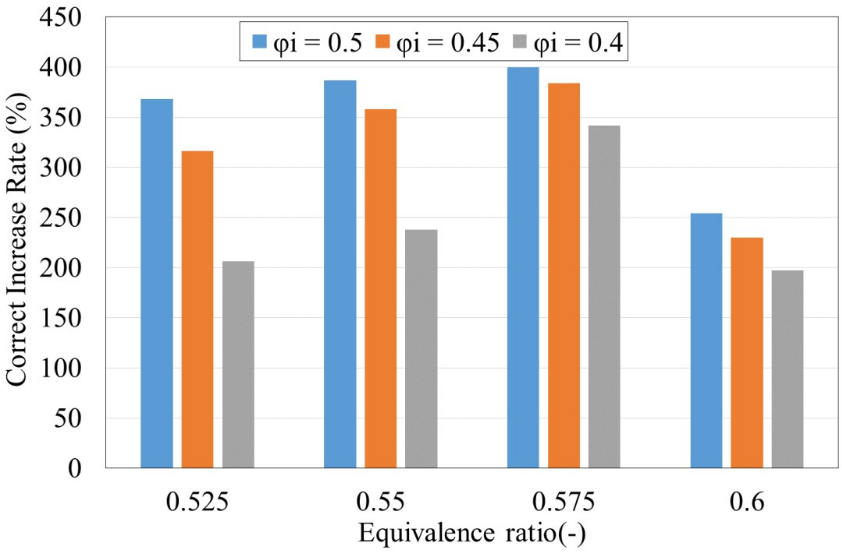



*Fig. 12. Correct increase rate*

Figure 12 shows the correct increase rate against the equivalence ratio as a function of equivalence ratio of mixture injection. From this figure, the highest value is also obtained with equivalence ratio of injection mixture of 0.575. This result also indicated that the most suitable conditions exit for combustion improvement near the flammability limit by using the mixture injection.

## 4. Conclusions

Experiments have been carried out to examine the influence of combination flow and mixture injection on flame behaviour and flame propagation speed for lean premixed propane-air mixtures in a combustion tube.

The mail conclusions are as follows: 1) The Average flame speed with the swirl flow is remarkably increased as compared with the case of laminar flow; 2) The Average flame speed by using the combination flow is bigger than that of the swirl flow; 3) By changing the combination flow intensity, it is possible to control the flame speed; 4) The flame speed by using injection of premixed mixture to flame front is higher than that of laminar flame speed; 5) The most suitable conditions exit for combustion improvement near the flammability limit by using premixed mixture injection.

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