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Experimental Study about the Effect of Crucible Size Changing on the Solar Cells Production Line Efficiency, Used in Polycrystalline and Mono-Like Crystalline Solar Panels According to the Hot Zone Space Limitation of the Melting Furnaces

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Experimental Study about the Effect of Crucible Size Changing on the Solar Cells Production Line Efficiency, used in Polycrystalline and Mono-Like Crystalline Solar Panels according to the Hot Zone Space Limitation of the Melting Furnaces

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***Abstract*— Considering the increase in environmental pollutants and its effects on the climate change and environment, the world community is moving towards reducing the use of fossil fuels and increasing the use of renewable energies, especially solar energy, with a great importance due to its accessibility. In this regard and to increase the efficiency of the polycrystalline and mono-like crystalline solar cells' production line, an experimental study on the crucible sizes was conducted by Islamic Azad University, Central Tehran Branch, and important results were obtained. This experimental research was done on the 100 silicon melting furnaces (TCVP4 and TCVP5 Chambers types that crucible sizes of G5 (837x837x455mm) and G6 (1015x1015x560mm) use in them.). Following this experimental study and considering hot zone space limitation of the melting furnaces, by changing the sizes of used crucibles, the silicon block loss that was from 12.3% to 43.9% in different crucible and solar cell sizes decreased from 10.1% to 23.7%. These changes caused to improve the quality of the solar cells and increase the grade of them. Besides, by using 4,000,000kg silicon as this production line's row material, the polycrystalline solar cells' production efficiency that was from 744MW to 927MW during 218 to 293 working days increased from 913MW to 1048MW during 297 to 302 working days. These results are able to create considerable changes in the solar energy industry.**

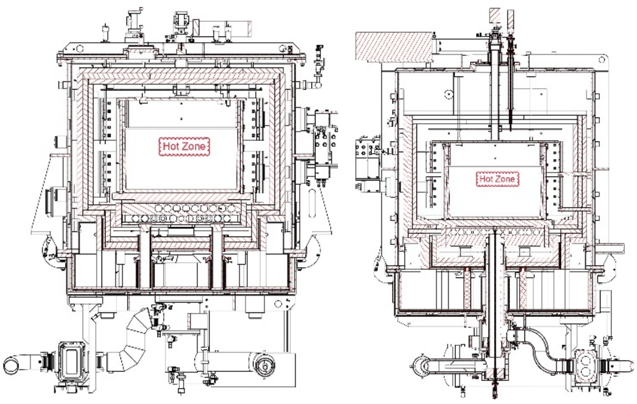
Keywords*— *Polycrystalline Solar Cells, Mono-Like Crystalline Solar Cells, Solar Cells' Production Line Efficiency, Crucible Size, Hot Zone Space Limitation of the Melting Furnaces

I. Introduction

To decreasing environmental pollutants and preserving from the environment, the world society is moving forwards to use clean and renewable energies such as solar energy, and various generations of solar panels have been produced up to now. However, the used solar cells' life time in these panels as well as their electrical efficiency decreases exposed to sunlight and due to increased temperature on the surface of the panels. Therefore, the manufacturers compete to solve this problem [1]. Zhang and his colleagues believe that photovoltaic-thermal modules are able to collect and convert a higher percentage of solar energy compared to solar panels and collectors in an identical absorption area that this matter causes to heat and power production with a low cost and high efficiency [2], and it has less payback period in comparison with photovoltaic systems and collectors [3,4]. In this regard, during experimental and theoretical studies conducted in Islamic Azad University, Central Tehran Branch, direct contact water spool was installed under solar panels from 2013 to 2022 to increase the life time, electrical and thermal efficiencies of the photovoltaic panels. During these studies, the average voltage production increased from 80% to 91% and the average amperage production increased from 71% to 84%. Meanwhile, its output hot water with a 99°C temperature was used as a solar water heater [5-13]. However, cooling of panels in this way to increase solar cells' life time and electrical efficiency cannot be justified in large-scale production and it is not applicable to executive projects. Therefore, fundamental studies on the solar cells production process are important to solve this problem and it will be possible just by experimental studies and trial and error in the related factories which are producing different types of solar cells. V. Parra and his colleagues have studied on the trends in crystalline silicon growth on 2013 that the result of this study was a higher efficiency of the photovoltaic cells and reducing in costs of production [14]. Y. C. Wu V. and his colleagues have studied on the effect of seed arrangements on the quality of n-type mono-like silicon grown by directional solidification on 2016 and as a result, the seed junction with large tilt angles had little effect on the defect generation, and the best tilt angle ranged from 10° to 30°. Except for the area near the 0° tilt angle, the best life time of the wafer after gettering could be greater than 3ms [15]. Fang Zhang and his colleagues have studied on the designing functional Σ13 grain boundaries at seed junctions for high-quality cast quasi-single crystalline silicon on 2019 and they found in this study that the generation of dislocation clusters and sub-GBs from the seed junctions is significantly suppressed owing to the low energy barrier potential of the Σ13 GB. Although some twins could generate from the vertical Σ13 GB, they will not give a bad influence on the ingot quality. The efficiency of solar cells was with an average value of 20.1% in industrial circles [16]. However, no study has been conducted up to now on the effect of changing in crucible size considering to the hot zone space limitation of the Melting Furnaces on the solar cells production line efficiency which are using in polycrystalline and mono-like crystalline solar panels. In this regard, the process of solar cells manufacturing has been studied. To producing polycrystalline and mono-like crystalline cells, silicon lumps should be melted in the special furnaces and converted to polycrystalline and mono-like crystalline solar cells. Therefore, during this study, 20 melting furnaces (TCVP4 Chamber type with crucible size of G5 (837x837x455mm)), 30 melting furnaces (TCVP5 Chamber type with crucible size of G5 (837x837x455mm)) and 50 melting furnaces (TCVP5 Chamber type with crucible size of G6 (1015x1015x560mm)) have been studied. These 100 furnaces are able to produce 700MW from M2 (157mm x 157mm x 180μm) cells or 780MW from M6 (166mm x 166mm x 180μm) cells or 810MW from M10 (182mm x 182mm x 180μm) cells or 820MW from M12 (210mm x 210mm x 180μm) cells or a combination of these states in the 330 working days that is equal to 8000 hours in a year

II. Methods and Principles

As indicated in the Figures 1 and 2, TCVP4 and TCVP5 Chambers types are furnaces with a limited space in the hot zone area and this limitation is one of the principles in the designing of a polycrystalline and mono-like crystalline solar cells production line.

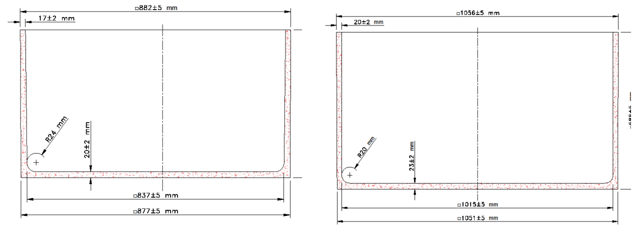


A) TCVP4 Chamber B) TCVP5 Chamber

Fig. 1. A Scheme of TCVP4 and TCVP5 Chamber Melting Furnaces

Fig. 2. A Sample of TCVP Chamber Melting Furnaces

As indicated in the Figures 3 and 4, the crucibles with the sizes of G5 (837x837x455mm) and G6 (1015x1015x560mm) are used to melt silicon lumps in the mentioned furnaces.



A) G5 (837x837x455mm) B) G6 (1015x1015x560mm)

Fig. 3. A Scheme of Crucibles used in TCVP4 and TCVP5 Chamber Melting Furnaces

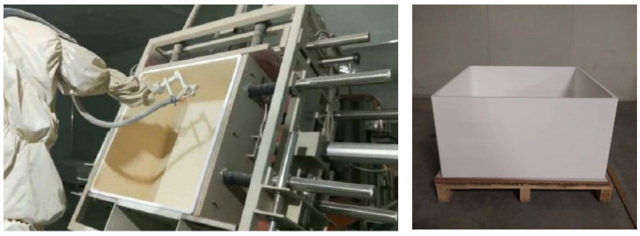


Fig. 4. A Sample of Crucible used in TCVP Chamber Melting Furnaces

The results of this production line before changing the size of crucibles are provided in Tables 1 and 2. Production and Block Waste Percentages in these tables are for one crucible.

As indicated in the Tables 1 and 2, after every silicon lump melting, one special size and grade of solar cells will be created by converting the silicon block to the solar cells by special saws (according to the Figure 5) that the molecular structure of different grades is provided in Fig. 6. Meanwhile, the silicon block waste in different stages is from 12.3% up to 43.9% during a complete production stage that should be recycled again and its quality will be decreased during each stage of recycling that this matter is not acceptable by Quality Control Department of Production Line.

TCVP4 Chamber (Quantity: 20) & TCVP5 Chamber (Quantity: 30)			
The Used Crucible Size for These Chambers	**Cell Size (Thickness 180μm)**	**Production Percentage**	**Block Waste Percentage**
Crucible G5 (837x837x455mm)	Or M2 (157x157mm)	87.7%	12.3%
	Or M6 (166x166mm)	62.9%	37.1%
	Or M10 (182x182mm)	75.7%	24.3%
	Or M12 (210x210mm)	56.7%	43.3%
TCVP5 Chamber (Quantity: 50)			
The Used Crucible Size for These Chambers	**Cell Size (Thickness 180μm)**	**Production Percentage**	**Block Waste Percentage**
Crucible G6 (1015x1015x560mm)	Or M2 (157x157mm)	85.9%	14.1%
	Or M6 (166x166mm)	66.9%	33.1%
	Or M10 (182x182mm)	80.4%	19.6%
	Or M12 (210x210mm)	68.5%	31.5%

Table 1. The Production Amount of Polycrystalline Solar Cells by one Crucible

TCVP4 Chamber (Quantity: 20) & TCVP5 Chamber (Quantity: 30)			
The Used Crucible Size for These Chambers	**Cell Size (Thickness 180µm)**	**Grade Production Percentage**	**Block Waste Percentage**
Crucible G5 (837x837x455mm)	Or M2 (157x157mm)	Grade A: 42.1% Grade B: 0.0% Grade C: 14.0%	43.9%
	Or M6 (166x166mm)	Grade A: 47.2% Grade B: 0.0% Grade C: 15.7%	37.1%
	Or M10 (182x182mm)	Grade A: 56.7% Grade B: 0.0% Grade C: 18.9%	24.3%
	Or M12 (210x210mm)	Grade A: 31.5% Grade B: 0.0% Grade C: 25.2%	43.3%
	All round M2 (157x157mm) & Center M2 (157x157mm)	M2 Grade A: 31.6% M2 Grade B: 12.6% M2 Grade C: 43.5%	12.3%
	All round M2 (157x157mm) & Center M6 (166x166mm)	M6 Grade A: 15.7% M2 Grade B: 12.6% M2 Grade C: 43.5%	28.2%
	All round M2 (157x157mm) & Center M10 (182x182mm)	M10 Grade A: 18.9% M2 Grade B: 12.6% M2 Grade C: 43.5%	25.0%
	All round M2 (157x157mm) & Center M12 (210x210mm)	M12 Grade A: 25.2% M2 Grade B: 12.6% M2 Grade C: 43.5%	18.7%
	All round M6 (166x166mm) & Center M2 (157x157mm)	M2 Grade A: 14.0% M6 Grade B: 9.4% M6 Grade C: 37.8%	38.8%
	All round M6 (166x166mm) & Center M6 (166x166mm)	M6 Grade A: 15.7% M6 Grade B: 9.4% M6 Grade C: 37.8%	37.1%
	All round M6 (166x166mm) & Center M10 (182x182mm)	M10 Grade A: 18.9% M6 Grade B: 9.4% M6 Grade C: 37.8%	33.9%
	All round M6 (166x166mm) & Center M12 (210x210mm)	M12 Grade A: 25.2% M6 Grade B: 9.4% M6 Grade C: 37.8%	27.6%
	All round M10 (182x182mm) & Center M2 (157x157mm)	M2 Grade A: 14.0% M10 Grade B: 11.3% M10 Grade C: 45.4%	29.2%
	All round M10 (182x182mm) & Center M6 (166x166mm)	M6 Grade A: 15.7% M10 Grade B: 11.3% M10 Grade C: 45.4%	27.5%
	All round M10 (182x182mm) & Center M10 (182x182mm)	M10 Grade A: 18.9% M10 Grade B: 11.3% M10 Grade C: 45.4%	24.3%
	All round M10 (182x182mm) & Center M12 (210x210mm)	M12 Grade A: 25.2% M10 Grade B: 11.3% M10 Grade C: 45.4%	18.1%
	All round M12 (210x210mm) & Center M2 (157x157mm)	M2 Grade A: 14.0% M12 Grade B: 7.6% M12 Grade C: 42.8%	35.6%
	All round M12 (210x210mm) & Center M6 (166x166mm)	M6 Grade A: 15.7% M12 Grade B: 7.6% M12 Grade C: 42.8%	33.9%
	All round M12 (210x210mm) & Center M10 (182x182mm)	M10 Grade A: 18.9% M12 Grade B: 7.6% M12 Grade C: 42.8%	30.7%
	All round M12 (210x210mm) & Center M12 (210x210mm)	M12 Grade A: 6.3% M12 Grade B: 7.6% M12 Grade C: 42.8%	43.3%
TCVP5 Chamber (Quantity: 50)			
The Used Crucible Size for These Chambers	**Cell Size (Thickness 180µm)**	**Grade Production Percentage**	**Block Waste Percentage**
Crucible G6 (1015x1015x560mm)	Or M2 (157x157mm)	Grade A: 50.1% Grade B: 0.0% Grade C: 9.5%	40.4%
	Or M6 (166x166mm)	Grade A: 56.2% Grade B: 0.0% Grade C: 10.7%	33.1%
	Or M10 (182x182mm)	Grade A: 67.5% Grade B: 0.0% Grade C: 12.9%	19.6%
	Or M12 (210x210mm)	Grade A: 51.4% Grade B: 0.0% Grade C: 17.1%	31.5%
	All round M2 (157x157mm) & Center M2 (157x157mm)	M2 Grade A: 38.2% M2 Grade B: 11.4% M2 Grade C: 36.3%	14.1%
	All round M2 (157x157mm) & Center M6 (166x166mm)	M6 Grade A: 24.1& M2 Grade B: 11.4% M2 Grade C: 36.3%	28.2%
	All round M2 (157x157mm) & Center M10 (182x182mm)	M10 Grade A: 28.9% M2 Grade B: 11.4% M2 Grade C: 36.3%	23.4%
	All round M2 (157x157mm) & Center M12 (210x210mm)	M12 Grade A: 38.9% M2 Grade B: 11.4% M2 Grade C: 36.3%	13.8%
	All round M6 (166x166mm) & Center M2 (157x157mm)	M2 Grade A: 38.2% M6 Grade B: 9.6% M6 Grade C: 33.2%	19.0%
	All round M6 (166x166mm) & Center M6 (166x166mm)	M6 Grade A: 24.1% M6 Grade B: 9.6% M6 Grade C: 33.2%	33.1%
	All round M6 (166x166mm) & Center M10 (182x182mm)	M10 Grade A: 28.9% M6 Grade B: 9.6% M6 Grade C: 33.2%	28.3%
	All round M6 (166x166mm) & Center M12 (210x210mm)	M12 Grade A: 38.5% M6 Grade B: 9.6% M6 Grade C: 33.2%	18.7%
	All round M10 (182x182mm) & Center M2 (157x157mm)	M2 Grade A: 21.5% M10 Grade B: 11.6% M10 Grade C: 39.9%	27.1%
	All round M10 (182x182mm) & Center M6 (166x166mm)	M6 Grade A: 24.1% M10 Grade B: 11.6% M10 Grade C: 39.9%	24.5%
	All round M10 (182x182mm) & Center M10 (182x182mm)	M10 Grade A: 28.9% M10 Grade B: 11.6% M10 Grade C: 39.9%	19.6%
	All round M10 (182x182mm) & Center M12 (210x210mm)	M12 Grade A: 17.1% M10 Grade B: 11.6% M10 Grade C: 39.9%	31.4%
	All round M12 (210x210mm) & Center M2 (157x157mm)	M2 Grade A: 21.5% M12 Grade B: 10.3% M12 Grade C: 41.1%	27.2%
	All round M12 (210x210mm) & Center M6 (166x166mm)	M6 Grade A: 24.1% M12 Grade B: 10.3% M12 Grade C: 41.1%	24.6%
	All round M12 (210x210mm) & Center M10 (182x182mm)	M10 Grade A: 28.9% M12 Grade B: 10.3% M12 Grade C: 41.1%	19.7%
	All round M12 (210x210mm) & Center M12 (210x210mm)	M12 Grade A: 17.1% M12 Grade B: 10.3% M12 Grade C: 41.1%	31.5%

Table 2. The Production Amount of Mono-Like Crystalline Solar Cells by one Crucible

Fig. 5. Sample of Silicon Blocks Cutting by Special Saws

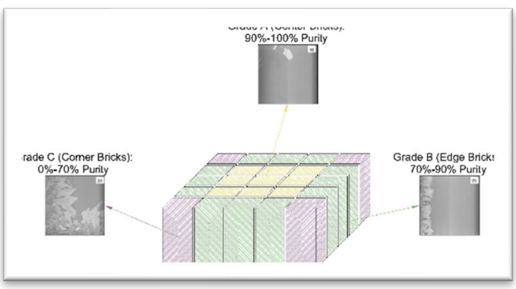


Fig. 6. The Molecular Structure of the Different Grades of Polycrystalline and Mono-Like Crystalline Solar Cells

Considering that a M2 polycrystalline solar cell will be produced equivalent to 4.42W, a M2 mono-like crystalline 4.95W, a M6 polycrystalline 5.51W, a M6 mono-like crystalline 5.90W, a M10 polycrystalline 6.86W, a M10 mono-like crystalline 7.15W, a M12 polycrystalline 9.26W and a M12 mono-like crystalline 9.61W, therefore, during 330 working days that is equal to 8000 working hours per a year, to producing 700MW of M2 (157mm x 157mm x 180µm) cells, 3667 pieces of G5 (837x837x455mm) crucible and 2778 pieces of G6 (1015x1015x560mm) crucible and totally 4,582,895Kg silicon lumps are needed, and to producing 780MW of M6 (166mm x 166mm x 180µm) cells, 3299 pieces of G5 (837x837x455mm) crucible and 2499 pieces of G6 (1015x1015x560mm) crucible and totally 4,122,984Kg silicon lumps, to producing 810MW of M10 (182mm x 182mm x 180µm) cells, 3185 pieces of G5 (837x837x455mm) crucible and 2413 pieces of G6 (1015x1015x560mm) crucible and totally 3,980,758Kg silicon lumps, to producing 820MW of M12 (210mm x 210mm x 180µm) cells, 3141 pieces of G5 (837x837x455mm) crucible and 2380 pieces of G6 (1015x1015x560mm) crucible and totally 3,926,220Kg silicon lumps or a combination of these states are needed. Therefore, considering the high volume of consumed silicon lump and crucible, to decreasing silicon waste and increasing the quality and efficiency of the solar cells, the size of used crucibles in the production line were studied and remarkable results were obtained.

III. Results

According to the previous tables and at the first glance, it is clear that the efficiency of the production line will be changed by upgrading the furnaces. Because the body structure of the TCVP4 Chamber furnaces is not changeable, but TCVP5 Chamber furnaces that the G5 (837x837x455mm) crucibles are usable in their hot zone area and they are 30 pieces, are upgradable to another TCVP5 Chamber furnaces that the G6 (1015x1015x560mm) crucibles are usable in their hot zone area. With this change, the number of needed crucibles to producing 700MW of M2 (157mm x 157mm x 180µm) cells will be changed to 1252 pieces of G5 (837x837x455mm) crucible and 3794 pieces of G6 (1015x1015x560mm) crucible, to producing 780MW of M6 (166mm x 166mm x 180µm) cells will be changed to 1255 pieces of G5 (837x837x455mm) crucible and 3804 pieces of G6 (1015x1015x560mm) crucible, to producing 810MW of M10 (182mm x 182mm x 180µm) cells will be changed to 1259 pieces of G5 (837x837x455mm) crucible and 3814 pieces of G6 (1015x1015x560mm) crucible and to producing 820MW of M12 (210mm x 210mm x 180µm) cells will be changed to 1257 pieces of G5 (837x837x455mm) crucible and 3808 pieces of G6 (1015x1015x560mm) crucible which are fewer crucibles compared to the previous state and as indicated in the previous tables and diagrams, the silicon waste will be decreased and the efficiency of the final product will be increased in this state. However, with a more precise look, the main solution to solve this problem is hidden in the crucible sizes. During this experimental study about polycrystalline and mono-like crystalline solar cells production line and after many trials and errors, to reducing silicon waste and to increasing the quality and efficiency of the solar cells, the most optimal crucible sizes were selected according to Tables 3 and 4. It is worth mentioning that these sizes are not commonly available in the market, they should be produced and because of the increasing the profit of the production line, their production is economical.

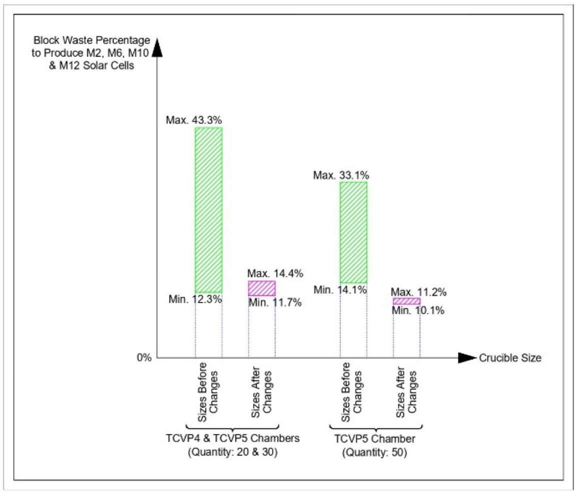
TCVP4 Chamber (Quantity: 20) & TCVP5 Chamber (Quantity: 30)			
The Used Crucible Size for These Chambers	**Cell Size (Thickness 180µm)**	**Production Percentage**	**Block Waste Percentage**
Crucible G5 (834x834x455mm)	Just M2 (157x157mm)	88.3%	11.7%
Crucible G4 (715x715x455mm)	Just M6 (166x166mm)	86.2%	13.8%
Crucible G5 (779x779x455mm)	Just M10 (182x182mm)	87.3%	12.7%
Crucible G4 (681x681x455mm)	Just M12 (210x210mm)	85.6%	14.4%
TCVP5 Chamber (Quantity: 50)			
The Used Crucible Size for These Chambers	**Cell Size (Thickness 180µm)**	**Production Percentage**	**Block Waste Percentage**
Crucible G6 (992x992x560mm)	Just M2 (157x157mm)	89.9%	10.1%
Crucible G6 (881x881x560mm)	Just M6 (166x166mm)	88.8%	11.2%
Crucible G6 (961x961x560mm)	Just M10 (182x182mm)	89.7%	10.3%
Crucible G6 (891x891x560mm)	Just M12 (210x210mm)	88.9%	11.1%

Table 3. The Production Amount of Polycrystalline Solar Cells from One Crucible after Changing the Size of the Production Line Crucibles

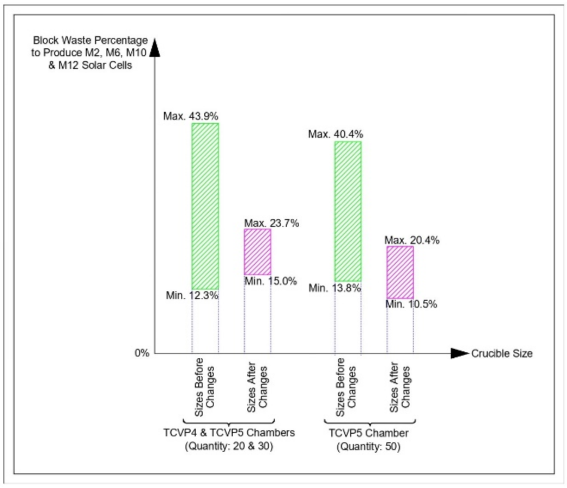
TCVP4 Chamber (Quantity: 20) & TCVP5 Chamber (Quantity: 30)			
The Used Crucible Size for These Chambers	**Cell Size (Thickness 180µm)**	**Grade Production Percentage**	**Block Waste Percentage**
Crucible G4 (680x680x455mm)	All round M2 (157x157mm) & Center M2 (157x157mm)	M2 Grade A: 21.25% M2 Grade B: 42.5% M2 Grade C: 21.25%	15%
Crucible G4 (698x698x455mm)	All round M2 (157x157mm) & Center M6 (166x166mm)	M6 Grade A: 22.6% M2 Grade B: 40.3% M2 Grade C: 20.2%	16.9%
Crucible G5 (730x730x455mm)	All round M2 (157x157mm) & Center M10 (182x182mm)	M10 Grade A: 24.9% M2 Grade B: 36.9% M2 Grade C: 18.4%	19.8%
Crucible G5 (786x786x455mm)	All round M2 (157x157mm) & Center M12 (210x210mm)	M12 Grade A: 28.6% M2 Grade B: 31.8% M2 Grade C: 15.9%	23.7%
TCVP5 Chamber (Quantity: 50)			
The Used Crucible Size for These Chambers	**Cell Size (Thickness 180µm)**	**Grade Production Percentage**	**Block Waste Percentage**
Crucible G6 (994x994x560mm)	All round M2 (157x157mm) & Center M2 (157x157mm)	M2 Grade A: 39.8% M2 Grade B: 39.8% M2 Grade C: 9.9%	10.5%
Crucible G6 (864x864x560mm)	All round M2 (157x157mm) & Center M6 (166x166mm)	M6 Grade A: 33.2% M2 Grade B: 39.5% M2 Grade C: 13.2%	14.1%
Crucible G6 (912x912x560mm)	All round M2 (157x157mm) & Center M10 (182x182mm)	M10 Grade A: 35.8% M2 Grade B: 35.4% M2 Grade C: 11.8%	16.9%
Crucible G6 (996x996x560mm)	All round M2 (157x157mm) & Center M12 (210x210mm)	M12 Grade A: 40% M2 Grade B: 29.7% M2 Grade C: 9.9%	20.4%

Table 4. The Production Amount of Mono-Like Crystalline Solar Cells from One Crucible after Changing the Size of the Production Line Crucibles

As indicated in Tables 1 and 2, after every silicon lump melting and converting the silicon block to the solar cells by special saws, two types of special size and grade of solar cells will be producible. Also, silicon block waste will be from 10.1% to 23.7% in the different states and during a production stage that according to the Diagrams 3 and 4, there is 2.2% to 20.2% decrease in waste compared to the primary state of production.



Dia. 1. The Decrease Amount in the Silicon Block Waste, in one Production Stage of Polycrystalline Solar Cells and after Changing the Production Line Crucible Size, compared to the Primary Production State

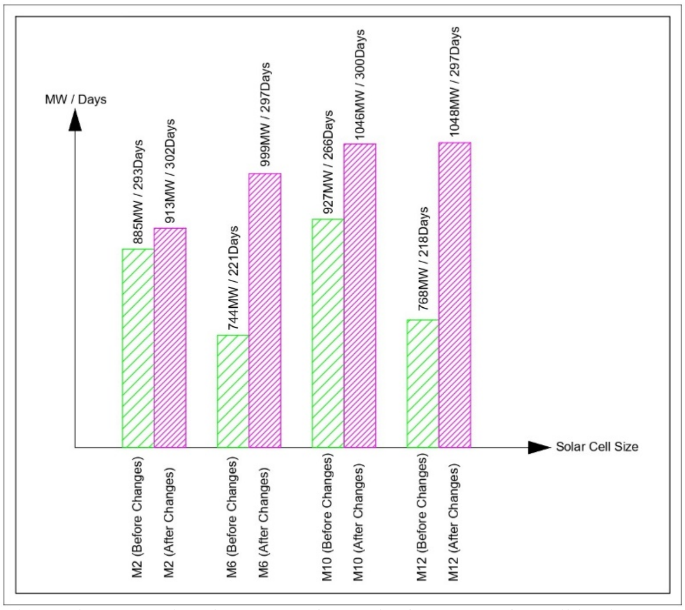


Dia. 2. The Decrease Amount in the Silicon Block Waste, in one Production Stage of Mono-Like Crystalline Solar Cells and after Changing the Production Line Crucible Size, compared to the Primary Production State

Therefore, as indicated in Table 5 and Diagram 3, if the constant amount of 4,000,000Kg silicon lumps is entered into a polycrystalline solar cells production line which has 100 furnaces with mentioned dimensions, by using G5 (837x837x455mm) and G6 (1015x1015x560mm) crucibles at the primary state and considering 12.3% and 43.3% waste, the amount of 2,572,025Kg to 3,461,624Kg of raw materials will be useful and consumable at different states which will be able to produce 744MW to 927MW polycrystalline solar cells during 218 to 293 working days. But at the secondary state and by using G4 (681x681x455mm), G4 (715x715x455mm), G5 (779x779x455mm), G5 (834x834x455mm), G6 (881x881x560mm), G6 (891x891x560mm), G6 (961x961x560mm) and G6 (992x992x560mm) crucibles, considering 10.1% and 14.4% waste, the amount of 3,513,515Kg to 3,572,654Kg of raw materials will be useful and consumable at different states which will be able to produce 913MW to 1048MW polycrystalline solar cells during 297 to 302 working days. The results for the production of mono-like crystalline solar cells and considering to producing of two sizes of solar cells at least and at the same time and considering the combination of previous states, will be between of the minimum and maximum of the mentioned results.

Cell Size (Thk. 180µm)	The Used Crucible Size to Produce Solar Cells	Volume Percentage of Raw Material for each Crucible	Useful Weight of Raw Material after Wastes Deducting	Final Production Result	Number of Working Days to Produce
Before Changes (First Status)					
M2 (157x157mm)	Crucible G5 (837x837x455mm)	35.588%	3461623.36 Kg	885 MW	293 Days
	Crucible G6 (1015x1015x560mm)	64.412%			
M6 (166x166mm)	Crucible G5 (837x837x455mm)	35.588%	2619059.20 Kg	744 MW	221 Days
	Crucible G6 (1015x1015x560mm)	64.412%			
M10 (182x182mm)	Crucible G5 (837x837x455mm)	35.588%	3149094.56 Kg	927 MW	266 Days
	Crucible G6 (1015x1015x560mm)	64.412%			
M12 (210x210mm)	Crucible G5 (837x837x455mm)	35.588%	2572024.64 Kg	768 MW	218 Days
	Crucible G6 (1015x1015x560mm)	64.412%			
After Changes (Second Status)					
Cell Size (Thk. 180µm)	**The Used Crucible Size to Produce Solar Cells**	**Volume Percentage of Raw Material for each Crucible**	**Useful Weight of Raw Material after Wastes Deducting**	**Final Production Result**	**Number of Working Days to Produce**
M2 (157x157mm)	Crucible G5 (834x834x455mm)	36.479%	3572653.44 Kg	913 MW	302 Days
	Crucible G6 (992x992x560mm)	63.521%			
M6 (166x166mm)	Crucible G4 (715x715x455mm)	34.860%	3515745.60 Kg	999 MW	297 Days
	Crucible G6 (881x881x560mm)	65.140%			
M10 (182x182mm)	Crucible G5 (779x779x455mm)	34.806%	3554586.24 Kg	1046 MW	300 Days
	Crucible G6 (961x961x560mm)	65.194%			
M12 (210x210mm)	Crucible G4 (681x681x455mm)	32.186%	3513514.48 Kg	1048 MW	297 Days
	Crucible G6 (891x891x560mm)	67.814%			

Table 5. The Comparison between Before and After States of Crucible Sizes changing in the Final Production of Polycrystalline Solar Cells, for the Constant Amount of 4,000,000Kg Silicon Lumps as Row Material of the Production Line



Dia. 3. The Comparison between Before and After States of Crucible Sizes changing in the Final Production of Polycrystalline Solar Cells, for the Constant Amount of 4,000,000Kg Silicon Lumps as Row Material of the Production Line

Therefore, as indicated in Table 5 and Diagrams 1 to 3, the silicon block waste which is from 12.3% to 43.9% will be decreased from 10.5% to 23.7% at the different states, besides, polycrystalline solar cells production which is from 744MW to 927MW during 218 to 293 working days (resulting from 4,000,000Kg row material in the different states) will be increased from 913MW to 1048MW during 297 to 302 working days. So, if the results of this study will be applied in all production lines which are working in this industry, the net profit of the factories will be increased considerably and it will be unprecedented.

IV. Acknowledgement

This article is the result of experimental study of the authors of this research and all property and intellectual rights belong to Islamic Azad University, Central Tehran Branch, and every direct or indirect using from information of this research without the written consent from the responsible author and Islamic Azad University, Central Tehran Branch, has legal prosecution.

V. References

[1] S.Y. Wu, Q.L. Zhang, L. Xiao, F.H. Guo, "*A heat pipe photovoltaic/thermal (PV/T) hybrid system and its performance evaluation*", Energy and Buildings, September 18, 2011.

[2] X. Zhang, et al., "*Review of R&D progress and practical application of the solar photovoltaic/thermal (PV/T) technologies*", Renewable and Sustainable Energy Reviews, Vol. 16, No. 1, pp. 599-617, 2012.

[3] P. Dupeyrat, et al., "*Improvement of PV module optical properties for PV-thermal hybrid collector application*", Solar Energy Materials and Solar Cells, Vol. 95, No. 8, pp. 2028-2036, 2011.

[4] M.A. Hasan, K. Sumathy, "*Photovoltaic thermal module concepts and their performance analysis: a review*", Renewable and Sustainable Energy Reviews, Vol. 14, No. 7, pp. 1845-1859, 2010.

[5] M. Eftekhari Yazdi, E. Goudarzi Raad, I. Harsini, "*Thermosiphon solar water heater behavior in autumn (with two flat collectors and horizontal double glazed storage tank)*", *Second National Conference on wind and solar energy,* Tehran, Iran, February 21, 2013.

[6] M. Eftekhari Yazdi, E. Goudarzi Raad, I. Harsini, "*Experimental study of domestic thermosiphon solar water heater with two flat collectors*", *First national conference of Construction of the new facilities*, Kerman, Iran, February 23-24, 2013.

[7] M. Eftekhari Yazdi, H. Eskandar Zadeh, I. Harsini, E. Goudarzi Raad, "*Compare the behavior of thermosiphon solar water heater with two flat collectors and horizontal double glazed storage tank in the autumn and summer*", *Third International Conference on Emerging Trends in Energy Conservation,* March 2-3, 2014.

[8] M. Eftekhari Yazdi, H. Eskandar Zadeh, I. Harsini, **"***The behavior of thermosiphon solar water heater with two flat collectors and horizontal double glazed storage tank in summer*"**,** *Third International Conference on Emerging Trends in Energy Conservation,* March 2-3, 2014.

[9] H. Eskandarzadeh, M. Eftekhari Yazdi, I. Harsini, "*Islamic Azad University Central Tehran Branch, Solar water heater combined with open cycle photovoltaic thermal panel*", US Patent No. 85286, March 14, 2015.

[10] A. Soleymani Ashtiani, M. Eftekhari Yazdi, I. Harsini, "*Simulation and Analysis of Photovoltaic Thermal (PVT) Solar Panels Cooling Experimental Model with K-Omega Method*", Twelfth International Conference of Energy, 2018.

[11] A. Soleymani Ashtiani, M. Eftekhari Yazdi, I. Harsini, "*Simulation and Analysis of Photovoltaic Thermal (PVT) Solar Panels Cooling Experimental Model and Analysis of its Advantages and Disadvantages*", Fifth International Conference of Green Economy, 2018.

[12] A. Soleymani Ashtiani, M. Eftekhari Yazdi, I. Harsini, "*Simulation and Analysis of Photovoltaic Thermal (PVT) Solar Panels Cooling Experimental Model with K-Omega Method and Analysis of Its Advantages and Disadvantages*", International Journal of resistive economics, 2019.

[13] A. Soleymani Ashtiani, M. Eftekhari Yazdi, I. Harsini and M. Gharazadeh, "*Simulation and Analysis of Photovoltaic Thermal (PVT) Solar Panels and Comparison of Turbulence Models*", Easy Chair Website - A journal reviewing and publishing platform (England), 2022.

[14] V. Parra, T. Carballo, D. Cancillo, B. Moralejo, O. Martínez, J. Jiménez, J. Bullón, J. M. Míguez, R. Ordás, "*Trends in crystalline silicon growth for low cost and efficient photovoltaic cells*", Conference of Electron Devices (CDE), Spanish Conference on Solar Silicon Project, 2013.

[15] Y. C. Wu, A. Lan, C. F. Yang, C. W. Hsu, C. M. Lu, A. Yang, and C. W. Lan, "*Effect of Seed Arrangements on the Quality of n-Type Monolike Silicon Grown by Directional Solidification*", Crystal Growth & Design Journal (American Chemical Society, 2016.

[16] F. Zhang, X. Yu, C. Liu, S. Yuan, X. Zhu, Z. Zhang, L. Huang, Q. Lei, D. Hu, D. Yang, "*Designing functional Σ13 grain boundaries at seed junctions for high-quality cast quasi-single crystalline silicon*", Solar Energy Materials and Solar Cells Journal (ELSEVIER), 2019.