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Design of Hydrogen on Demand Production Generator Based on Aluminum Waste and Water Hydrolysis using VDI 2221 Method

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Abstract. Hydrogen is one of the transition energy sources and has an important role in the decarbonization of the global energy system. There are several methods of generating hydrogen such as reforming hydrocarbon, electrolysis of water as well as chemical reactions between active metals such as aluminum or primary hybrid solution. Hydrogen production from aluminum can provide an alternative way to produce hydrogen on demand. Hydrogen generator on demand is a generator that can produce hydrogen as needed, in other words the generator will only produce hydrogen when there is a demand. This research aims to design a hydrogen on demand generator with a more minimalist dropping mechanism to reduce blockage of aluminum powder so that it can overcome the weaknesses of the previous system. The method used in this research is the VDI 2221, which is a method with a systematic approach to solving problems and optimizing the use of materials and technology which is expected to facilitate a design. The result of this research is the design of a hydrogen on demand generator with a minimalistic dropping mechanism. From the results, it can be concluded that the VDI 2221 method is very helpful and facilitates of the design process and the realization of a hydrogen on demand generator design with minimalistic dropping mechanism, namely an automatic opening system supported by spring.

Keywords: *Hydrogen on Demand; Aluminum Waste; Hydrolysis; Generator Design; VDI 2221*.

1 Introduction

Hydrogen is one of the transition energy sources and has an important role in the decarbonization of the global energy system in [1]. Hydrogen is also the best fuel to get high performance from fuel cells in [2]. There are several methods of generating hydrogen such as reforming hydrocarbon, electrolysis of water as well as chemical reactions between active metals such as aluminum or primary hybrid solution in [3]. Hydrogen production from aluminum can provide an alternative

way to produce hydrogen on demand. Hydrogen generator on demand is a generator that can produce hydrogen as needed, in other words the generator will only produce hydrogen when there is demand. However, to date no sustainable generator solutions have been adopted by industry or consumers as an economically viable, financially attractive, and beneficial solution to society in [4]. However, Avrahami et al in [3] argue that the method of dropping aluminum powder continuously and controlled from time to time in two closed spaces has the potential to produce hydrogen on demand. In his research, it was stated that of the 5 design variations, the mechanism of dropping aluminum powder through a rotating disc was the best mechanism with an average H_2 flow rate of 420 ml/minute, but had a weakness, namely the blockage of aluminum powder between the discs, which interfered with the release of aluminum powder into the water container (cartridge reactor).

The design in this research aims to make a new generator that is better at refining previous research. Therefore the design of the generator must have more value than the previous generator, such as in terms of the mechanism and effectiveness of the generator. In designing a generator, a method can be used is the VDI 2221 method. The VDI 2221 method is a method used to design a product, including for designing hydrogen generators on demand because the VDI 2221 method can be used to overcome problems in a design by optimizing the material using and technology used in a design.Therefore, in this research designed a hydrogen on demand production generator with an update on the dropping mechanism with the aim of reducing the blockage of aluminum powder so that the expected hydrogen production will be more optimal.

2 Method

2.1 Flow chart Research

The research flowchart explains the outline of the research implementation methodology. The research sequence starts from; study literature, conclusions. The research sequence can be seen more clearly in Figure 1.

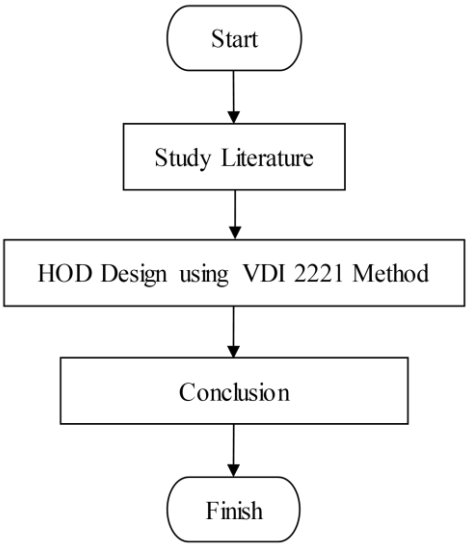


Figure 1 Flow chart research of design generator hydrogen on demand.

2.2 VDI 2221 Method

The design method in the Design of Hydrogen on Demand Production Generator Based on Aluminum Waste and Water Hydrolysis using VDI 2221 Method must be systematic so that it can fulfill several aspects such as tool safety, ease of use, ease of maintenance, and ease of repair. The VDI 2221 method (Verein Deutcher Ingenieure) written in a book by Gerhard Pahl and Wolfgang Beitz entitled Engineering Design: A Systematic Approach is a Systematic Method for Solving Problems. In the VDI 2221 method there are several phases, namely:

- Phase 1 : Classification of the Task (Clarification of the Task)
- Phase 2 : Conceptual Design
- Phase 3 : Form Design (Embodiment Concept)
- Phase 4 : Detailed Design (Detail Design)

The phases in the VDI 2221 method can be illustrated through the following flowchart, see figure 2:

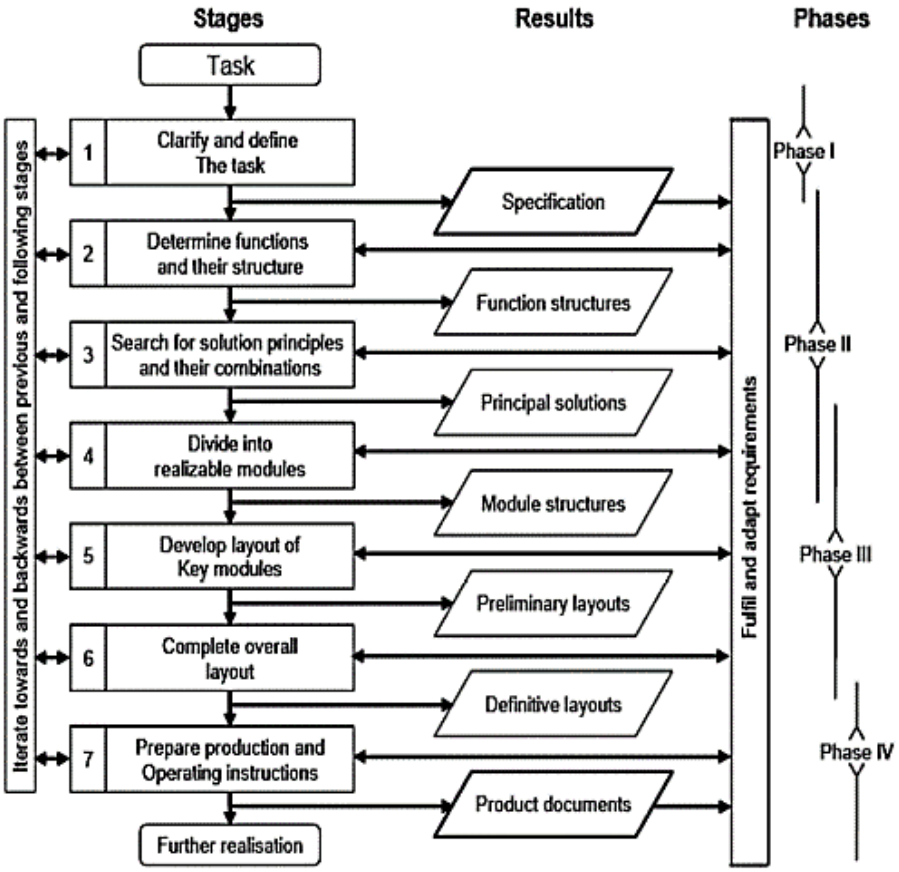


Figure 2 Flow chart of VDI 2221 method

3 Results and Discussion

3.1 Wish List

At this stage, an idea or wishes is carried out to realize a hydrogen generator that meets the specifications. The list of inclinations is arranged systematically into a list called a Wish List. Each specification is divided into 2 categories: D (Demands) dan W (Wishes), See Table 1.

Table 1 Wish list.

PARAMETER	SPESIFICATION	DEMAND (D) / WISHES (W)
GEOMETRY	Powder chamber height 163 mm	D
	Water chamber height 296 mm	D
	Diameter 150 mm	D
KINEMATIC	Can produce hydrogen 300 liter/minute	W
	Mixer blade upper dan mixer blade lower can operate together	D
	Driver motor DC 30 RPM	D
	Ball Bearing	D
MATERIAL	Tank stainless steel	D
	Elbow Plate	D
	Steel	D
	Wire springs	D
	Hex and SHCS Bolt	D
	Tank Acrylic	W
ASSEMBLY	Assembly system is easy to understand	D
	Easy to assembly - disassembly	D
MANUFACTURE	Manufacture in workshop (subcontract)	D
	Using standart part	D
	Easy to manufacture	D
	Manufacture in college	W
OPERATION	Easy to operate	D
	No special skills require	D
	Safe to use	D
	Full automatic	W
MAINTENANCE	Easy to refill	D
	Easy to clean	D
PRICE	Affordable for students	D

3.2 Abstraction

Abstraction is the formulation of the problem and analysis of the wish list. In the abstraction there are 5 steps, namely:

1. Eliminate all wishes (w) statement, see Table 2.

Table 2 Abstraction 1.

PARAMETER	SPESIFICATION	DEMAND (D) / WISHES (W)
GEOMETRY	Powder chamber height 163 mm	D
	Water chamber height 296 mm	D
	Diameter 150 mm	D
KINEMATIC	Mixer blade upper dan mixer blade lower can operate together	D
	Driver motor DC 30 RPM	D
	Ball Bearing	D
MATERIAL	Tank stainless steel	D
	Elbow Plate	D
	Steel	D
	Wire springs	D
	Hex and SHCS Bolt	D
ASSEMBLY	Assembly system is easy to understand	D
	Easy to assembly - disassembly	D
MANUFACTURE	Manufacture in workshop (subcontract)	D
	Using standart part	D
	Easy to manufacture	D
OPERATION	Easy to operate	D
	No special skills require	D
	Safe to use	D
MAINTENANCE	Easy to refill	D
	Easy to clean	D
PRICE	Affordable for students	D

2. Ignore wishes that have no direct impact to the main functions and constraints, see Table 3.

Table 3 Abstraction 2.

PARAMETER	SPESIFICATION	DEMAND (D) / WISHES (W)
GEOMETRY	Powder chamber height 163 mm	D
	Water chamber height 296 mm	D
	Diameter 150 mm	D

KINEMATIC	Mixer blade upper and mixer blade lower can operate together	D
MATERIAL	Driver motor DC 30 RPM	D
ASSEMBLY	Easy to assembly - disassembly	D
MANUFACTURE	Using standart part	D
OPERATION	Easy to operate	D
MAINTENANCE	Easy to refill	D
	Easy to clean	D

3. Change data quantitative into qualitative and make it a statement that is basic and of high quality, see Table 4.

Table 4 Abstraction 3.

PARAMETER	SPESIFICATION	DEMAND (D) / WISHES (W)
FUNCTION	Generator can generate hydrogen on demand	D
ASSEMBLY	Easy to assembly - disassembly	D
MANUFACTURE	Using standart part	D
OPERATION	Easy to operate	D
MAINTENANCE	Easy to refill	D
	Easy to clean	D

4. The results of step 3 above are then made more general, namely:
    - Generator can produce hydrogen on demand.
    - Generator uses standard parts so it is easy to assemble and disassemble.
    - Generator easy to maintain and operate.
5. Solve the problem in step 4 to be more neutral, namely the generator can produce hydrogen on demand more optimal.

3.3 Conceptual Design

3.3.1 Create generator function structure

Function structure is the general relationship between the input and output of a system that will carry out certain tasks. The function structure of the hydrogen generator is described in the form of a block diagram showing the input and output relationships as shown in Figure 2.

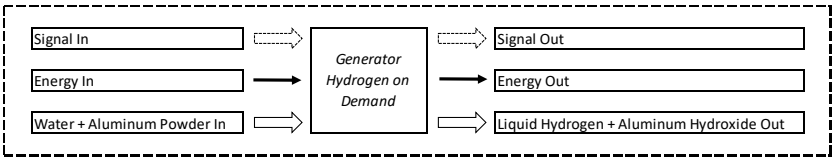


Figure 3 Function structure generator hydrogen on demand

3.3.2 Make the overall function of the generator

In this stage, a diagram of the overall function of the generator is described which can be provide into sub-functions, which can be seen in Figure 3.

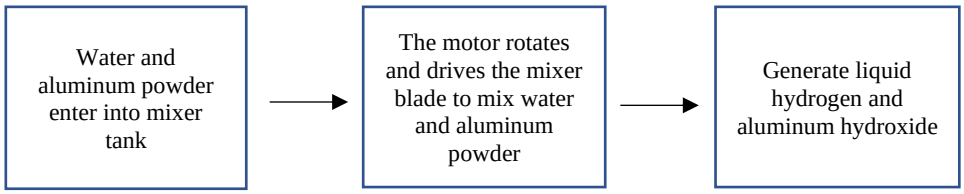


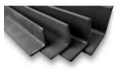
Figure 4 Sub function diagram of generator hydrogen on demand

3.3.3 Selection principle of generator function solutions

At this stage, we are looking for a principle solution to fulfill the sub-function of the hydrogen on demand generator that was made before, which can be seen in Table 5.

Table 5 Principles of sub function solutions.

No	Sub Function	Tool Part Functions	Principles Solutions		
			I	II	III
1	Dropping Mechanism	For dropping aluminum powder into water chamber	Automatic opening system (A)		
2	Chamber	Container to hold water and aluminum powder	Mild steel (A)	Acrylic (B)	Stainless steel (C)
3	Locking System	Components to bond the mixer tank and powder tank when assembled	 Quick Release System (A)		

4	Motor	Mixer blade drive	 High torque motor DC worm gear 12V 30RPM with encoder (A)	 Motor DC – kipas angina (B)	 Motor stepper (C)
5	Holder generator	Used to support a hydrogen generator	 Elbow (A)	 Hollow (B)	 Pipe (C)

From Table 5 several solution principles have been compiled, so that alternative combination variants are obtained. Then it is selected again to be realized in the right choice. Combination variants can be seen in Table 6.

Table 6 Principles solutions combination chart.

No	Sub Function	Variant I (A)	Variant II (B)	Variant III (C)
1	*Dropping Mechanism*	1A		
2	*Powder Tank*	2A	2B	2C
3	Pengikat antar tangki	3A		
4	*Motor*	4A	4B	4C
5	*Holder generator*	5A	5B	5C

From Table 6 the combination principal chart of the solution obtained the following concept combination variants:

Variant I = 1A + 2A + 3A + 4B + 5B
Variant II = 1A + 2B + 3A + 4C + 5C
Variant III = 1A + 2C + 3A + 4A + 5A

Description of the variant combination of concepts I, II, and III can be seen in Table 7 below.

Table 7 Solution principle combination diagram.

Variant	Description
I	The mixer and powder tank uses mild steel material, uses a quick release, uses a stepper motor and uses an iron pipe generator support and a dropping mechanism uses a spring.
II	The mixer and powder tank uses acrylic material, uses a quick release, uses a fan motor and uses a hollow iron generator support and a dropping mechanism uses a spring.
III	The mixer and powder tank uses stainless steel material, uses a quick release, uses a DC worm gear motor with encoder and uses an angle iron generator support and a dropping mechanism uses a spring.

3.3.4 Choice of variant combinations

Combination selection is assessing variations with existing requirements in order to get the best design concept, see Figure 4.

TABLE OF SELECTION OF CONCEPTS FOR VARIATIONS HYDROGEN GENERATOR

Decition Criteria :
(Y) Yes
(N) No
(?) Less Information
(!) Check Specification

Variations Design Concept

According to Overall of Function
According to Wish List
Production Cost
Easy to Assembly
Easy to Operate
Easy to Cleaning
Chamber Material Not Easy to Break

Decition

Variations	A	B	C	D	E	F	G	Remark	Result
V1	Y	Y	Y	Y	Y	N	N	Input water & powder in 1 hole	N
V2	Y	Y	N	Y	Y	N	N	Input water & powder in 1 hole, Cost is more expensive because it uses pulleys & belts	N
V3	Y	Y	Y	Y	Y	Y	Y	OK	Y

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Figure 5 Selection of the design concept variations

3.4 Embodiment Design

From the results of the table selection of the concept design variation and considering several factors to realize the design, it can be concluded that the best variation for design hydrogen on demand generator is variation 3. Then the next

step is to design sketch. The schematic design of hydrogen generator on demand can be see in Figure 5.

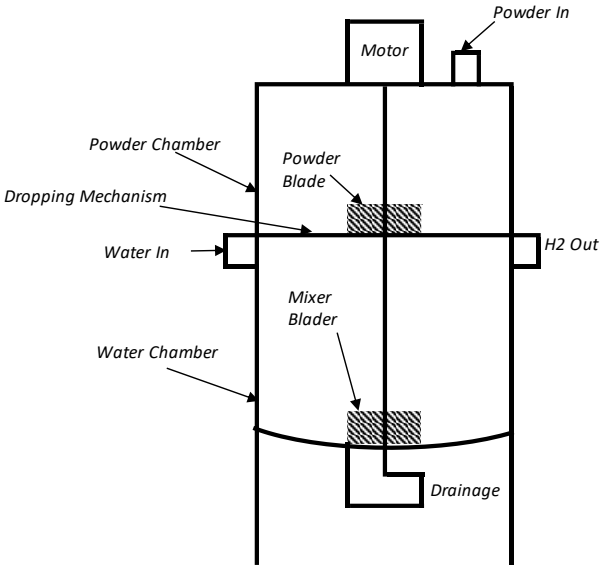

Figure 6 Design sketch of generator hydrogen on demand

3.5 Detail Design

Detail design is the final stage in a design namely in a documents that including such as tool drawings, detailed tool drawings, part lists, material specifications, operating systems, tolerances and other documents. The design generator made using the Siemens NX 7.5 software application. The main components of this tool can be see in Table 7.

Table 7 Main component of generator hydrogen on demand.

No	Part Name	Function
1	Mixer Tank	To hold water and aluminum powder when stireed
2	Mixer Blade	To stirring water
3	Powder Tank	To hold aluminum powder when stopped
4	Spring Holder	Part of powder valve so it can be open/close as automatically
5	Powder Valve	To open-close aluminum powder hole
6	Cover	Motor's cover guard or safety guard
7	Motor Holder	To hold motor
8	Mixer Upper Blade	To sweep aluminum powder so that it falls into the mixer tank area

3.5.1 Shop Drawing

Shop drawing of generator hydrogen on demand can be see in Figure 7 and Figure 8 as follows:

Figure 7 Detail 3D of generator hydrogend on demand

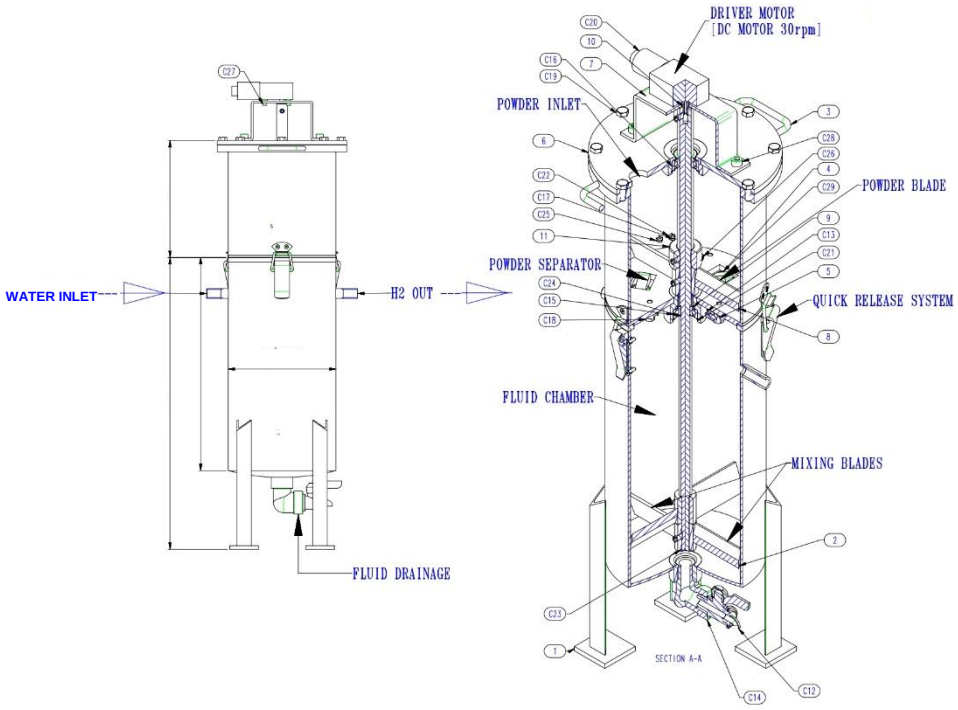

Figure 8 Detail assembly drawing of generator hydrogen on demand

3.5.2 Part List

Part List of generator hydrogen on demand can be seen in Table 8 as follows:

Table 8 Part list of generator hydrogen on demand.

No. Part	Name Of Part	Qty	Remark
1	00-Mix-01 [Mixer Tank]	1	Manufactur
2	00-Mix-02 [Mixer Blade]	2	Manufactur
3	00-Mix-03 [Powder Tank]	1	Manufactur
4	00-Mix-04 [Spring Holder]	3	Manufactur
5	00-Mix-05 [Powder Valve]	3	Manufactur
6	00-Mix-06 [Cover]	1	Manufactur
7	00-Mix-07 [Motor Holder]	1	Manufactur
8	00-Mix-08 [Mixer Blade Upper]	1	Manufactur
9	00-Mix-09 [Spacer]	1	Manufactur
10	00-Mix-10 [Shaft]	1	Manufactur
11	00-Mix-11 [Collar]	1	Manufactur
C12	Ball Valve 1_2 Bbpl2	1	Commercial Part
C13	Clgn5-40.0	3	Commercial Part
C14	Elbow 90 Deg-Sgpelh15a	1	Commercial Part
C15	Fag Bearing, 6201.27r	1	Commercial Part
C16	Fag Bearing, 6202.2zr	1	Commercial Part
C17	Fhcs Screw, Mjx10	12	Commercial Part
C18	Hex Bolt,M5x15	6	Commercial Part
C19	Hex Bolt,M6x15	8	Commercial Part
C20	High Torque Motor Dc Worm Gear 12v 30 Rpm With Encoder	1	Commercial Part
C21	Inner Snap Ring, M32x1.2	2	Commercial Part
C22	Nut M 3	12	Commercial Part
C23	Outer Snap Ring, S 10x0,6	1	Commercial Part
C24	Outer Snap Ring, S 12x1	1	Commercial Part
C25	Pkws4	3	Commercial Part
C26	Set Screw, M6x10	7	Commercial Part
C27	Shos Screw, M3x10	4	Commercial Part
C28	Shcs Screw, M6x10	4	Commercial Part
C29	Wire Spring Wm8-10	6	Commercial Part

4 Conclusion

Based on the results and discussion described above, it can be concluded that the VDI 2221 method is very helpful and facilitates the design process and the realization of a hydrogen on demand generator design with a minimalist dropping mechanism, namely an automatic opening system supported by spring system. In this research the method used is VDI 2221, so it is necessary to carry out further validation using the taguchi method to prove that the design is fit for purpose and is feasible for making a prototype. In addition, further research is needed to determine fluid dynamics or reactions that occur inside generator using computational fluid dynamic (CFD).

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